MIOCENE AND RECENT OPHIURA SKELETONS

A Dissertation
submitted to the Board of University Studies
of The Johns Hopkins University in conformity with
the requirements for the degree of
Doctor of Philosophy

BY
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February 1934

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INTRODUCTION

During the summer of 1929 many sections were taken and much collecting was done along the western shore of the Chesapeake Bay and its tributaries. These sections were primarly used in connection with heavy mineral determination. In the fall of 1930 I started to work on the paleontology of some of these collections and the following paper is partly the outgrowth of this work.

The area concerned is located on the western shore of the Chesapeake Bay near the southern end of the famous Calvert Cliffs in Calvert County. The Calvert Cliffs extend for about 35 miles along the Bay front, and consist of Miocene overlain by Pleistocene sands and gravels. As the entire section is very fossiliferous, Maryland has been taken for the type Miocene section of the Middle Atlantic coast. The three formations comprising the Miocene in Maryland are the Calvert, Choptank, and St. Mary's, grouped under the name of Chesapeake Group. The Yorktown formation which is the youngest Miocene in this general region is lacking in Maryland, but is extensively developed in Virginia. All these formations are more or less comfortable and dip about ten feet to a mile towards the southeast. Due to this dip the entire section can be studied conveniently.

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[1] The author is most grateful to Austin H. Clark of the U. S. National Museum for much good advice and recent material, to Dr. Hubert L. Clark of the Museum of Comparative Zoology for recent material and to Dr. Th. Mortensen for specimens of *Ophiura texturata* from the North Sea and of *Ophiura sarsii* from Davis Strait.

The St. Mary's formation which contains the Ophiurian which is the subject of the present paper, receives its name from St. Mary's County, Maryland. It is the youngest of the Miocene deposits in Maryland and is made up of sand, clay, and sandy-clay. It is mostly in the latter material that the prolific fossil-bearing zones are found. The formation has been correlated with the Middle Miocene (Tortonian) of Europe.

The particular section with which this paper is concerned was taken 8540 feet south of the Old Cove Point Wharf, which itself is about one mile south of Cove Point proper, Calvert County, Maryland. The section has a range of 52 feet vertically, of which only the lower half is very fossiliferous, the upper part being sand and clays.

The lack of general knowledge or printed description of the individual plates of recent forms forced me to dissect carefully a large number of recent specimens to obtain the desired information regarding the location, arrangement, size, and shape of each individual plate.

After I had picked out literally thousands of these different fossil plates and separated them according to their shape I was doubtful whether I was working with the plates from one species or several. However, after close scrutiny of the recent forms I found that certain plates, of different species of the same genera varied. With this as a guiding feature I studied the corresponding fossil plates and discovered that they would fall within the limits of variation of a single species. This proved that I was dealing with plates from one species alone. It might still be said, however, that I had plates from more than one species and that the characteristic plates had been either overlooked in picking them out or that they were not preserved. The probability of this being so is very slight, from the great number of plates found and from the fact that they were found in a section throughout a 15-foot vertical range. If more than

one species had lived in this locality during the deposition of fifteen or more feet of deposits certainly some of their plates would have been preserved along with those I found.

When it became obvious that I was dealing with only one species, the next question was to what genus and species all these diverse plates belonged. The first of these questions was settled easily for I found numerous fossil comb plates. It is only the genus Ophiura which possesses prominent comb plates and the plates that I found showed evidence of having been prominent. Now that the search had narrowed down to the one definite genus my real work began. There are 59 species of *Ophiura* and 18 species of *Homalophiura* listed by H. L. Clark in his Catalogue of Recent Ophiurans.[2] From all these I selected the most similar ones to the fossil. Of these I will try to give a comparison between each of the most similar recent ones and the fossil one, point by point, as I found them to differ. It is, I think, better to describe the fossil plates separately and take up later the comparison with the recent plates.

It soon became apparent that the plates from the St. Mary's formation represented an undescribed species. Indeed, as no Miocene species had been described from Atlantic North America this much was fairly obvious from the beginning.

For the purpose of citation this new species will be named at this point—*Ophiura marylandica.*

CLASSIFICATION

The paleontological work on the class Ophiuroidea has been meager. This becomes obvious as soon as one starts to look up the literature on this subject.

It is generally recognized that the classification of recent Ophiuroidea is somewhat unsatisfactory, and of fossil ones

[2] Clark, H. L., Catalogue of Recent Ophiuran, Mem. Mus. Comp. Zool., Harvard, Vol. xxv, No. 4, 1915.

there is practically none. The standard work on recent Ophiuroidea is that by Theodore Lyman in the Challenger Report.[3] Many capable writers have added to our knowledge of Ophiuroidea and new classifications have been offered since that Report was published, but they all have as a basis the work of Theodore Lyman. All the classifications are based upon the outward appearance and arrangement of the plates and not upon the character of the plates themselves, except some work by Matsumoto.[4] Very few of the scientists who have dealt with these animals have paid any attention to the actual shape of the separate plate.

From the work that was necessary for me to do in identifying my fossil plates I am convinced that if one took the time and trouble—for it would require a lot of both—to dissect the different recent species a new classification could be built up which would be better and more exact.

Schöndorf in 1910 proposed the subclass Auluroidea for certain fossil forms previously referred to the Ophiuroidea and in this he is followed by Schuchert[5] in his revision of the Paleozoic Stelleroidea. The Stelleroidea are segregated in three subclasses:—the Asteroidea, the Auluroidea and the Ophiuroidea. It is these last two subclasses with which I wish to deal.

There are certain ophiuran-like animals which have, in older publications, been placed under the Ophiuroidea, but which are not true Ophiurans as we distinguish them today. In these ophiuran-like animals the interradial margin of the disk is concaved and not distinctly separate as in the true

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[3] Lyman, T., Report on the Voyage of H. M. S. Challenger, Zool., Vol. v, 1882.

[4] Matsumoto, H., A new Classification of the Ophiuroidea: With description of New Genera and Species, Proc. Acad. Nat. Sci., Phila., Vol. xvii, p. 43, 1915.

[5] Schuchert, C., Revision of Paleozoic Stelleroidea with special reference to North American Asteroidea. Bull. 88, U. S. Nat. Mus., 1915.

ophiurans, where the margin of the disk is convex. They also possess open ambulacral furrows. These ophiuran-like animals have been placed by Schöndorf in a subclass which he has called *Auluroidea*. His definition of this subclass is as follows:—"The ambulacral watervascular system lies in a circular canal that is situated wholly within the ambulacralia medially between the adjoining columns of ossicles. From it diverge short side branches that either partially penetrate the substance of the individual ambulacrals, or lie in the suture between adjoining ambulacrals; in either case they extend into the ventrally open, broad ambulacral furrow. Ambulacrals free, not coössified, those of adjoining columns either alternate or opposite, but always directly opposite the adambulacrals. Ambulacrals ventrally composed of a medially situated, internally concavely hollowed-out body, which as the plates of the two columns are normally united, forms the medial ambulacral canal; and of a lateral process extending to the adambulacrals, with depressions on both sides of it in the ventral surfaces of the ambulacrals and adambulacrals. Disk with concave or convex margins, with or without marginal ossicles. When the latter are present, they never extend along the rays, but are wholly restricted to the disk. The rays on both sides are margined by the adambulacrals. Ventrally the rays have broad open ambulacrals furrows, bounded laterally by the adambulacrals. A typical madreporite lies in one of the ventral interradii." [6]

The open ambulacral furrow and the true madreporite, although situated on the ventral side in the Auluroidea, both point to a relationship with the Asteroidea, while the fact that the body cavity does not extend into the arms and the water vascular canal lies within the ossicles, points to the Ophiuroidea. For the above reasons it is believed that the Auluroidea is the link between the Asteroidea and the Ophiuroidea.

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[6] Schöndorf, F., Palaeontographica, Vol. 57, p. 60, 1910. Schuchert, C., U. S. Nat. Mus., Bull. 88, p. 213, 1915.

The Auluroidea make their appearance in the record during the latter part of the Ordovician and become extinct before the close of the Paleozoic, in the lower part of the Carboniferous. This subclass includes 30 genera and 59 species which have been classified by Schuchert [7] in the following manner:

Order LYSOPHIURAE

Family PROTASTERIDEA

Taeniaster, Eophiura, Bohemura, Palaeura, Protaster, Alepidaster, Grezoriura, Bundenbachia, Palaeophiomyxa.

Family PALAEOPHIURIDEA

Palaeophiura, Sturtzura, Eugasterella, Ptilonaster.

Family ENCRINASTERIDEA

Encrinaster.

Order STREPTOPHIUREA

Family OPHIURINIDEA

Ophiurina, Trematast er.

Family LAPWORTHURIDEA

Squamaster, Lapworthura, Sturtzaster, Bdellacoma, Rhopalocoma, Hallaster, Sympterura, Furcaster, Palastropecten.

Family EOLUIDIIDEA

Eoluidia, Eospondylus, Miospondylus.

Family AGANASTERIDEA

Aganaster.

Family CHOLASTERIDEA

Cholaster.

[7] Op. cit., p. 215.

The Asteroidea appear geologically a short time previous to the dawn of the Auluroidea, at the beginning of the Ordovician or the very late Cambrian, and have survived to the present. During this long span of time they have changed considerably and new genera have been evolved—but they have maintained their own special characteristics—and at present the seas swarm with them. In the Ordovician there were about 45 different species, but this number decreased in Silurian times, only to increase again in the Devonian period and then decrease in the Carboniferous. From this time on they increased until in the Cretaceous when they reached their zenith—in fossil record—only to be represented during the Tertiary by a relatively few forms.

Sometimes during the Devonian the Ophiuroidea evolved from the Auluroidea and started a long line of animals which are now embraced in 189 genera and 1412 species. Schuchert [8] in his classification has the Ophiuroidea starting in the Carboniferous as one family, the Onychasteridea, which contains only one genus:—Onychaster, that is segregated into five species. These five species are:—*O. flexilis, O. asper, O. barrisi, O. confragosus,* and *O. demissus.*

OPHIURANS AND THEIR HABITS

As I have just stated, the Stelleroidea are divided into three subclasses; the Asteroidea or the common sea-stars; the Auluroidea, an extinct Paleozioc group; and the Ophiuroidea. It is this last subclass with which this paper deals, the others being only mentioned as they bear directly on the Ophiurans.

The Ophiuroidea are for the most part small animals with five rays, though a few species have six, or even as many as nine rays, and others have six rays when young and five when adult. The six-rayed young dividing, each three-rayed half regenerating two rays. The Ophiuroidea occur in all seas at all depths; but they are not, like many sea stars,

[8] Op. cit., p. 268.

found exposed at low tide, nor do they extend into brackish or fresh water. They have a central disk which in contrast to that in the other two subclasses, is distinctly set off from the arms. All of the body systems are confined within the disk.

In a few genera the arms are stiff and only moderately flexible in the outer portion, in most cases the arms are very flexible, either horizontally or vertically, or more or less in both directions, and in some forms they may be coiled vertically in a close spiral.

The habits of the different types of Ophiuroidea are very varied. Many live concealed under stones or in crevises in rocks, among the roots of sea-weeds, or in the canals of sponges or in corals. Others live attached to gorgonians and other arborescent coelenterates, or to bryozoans, crinoids or echinoids, and many, in deep water, simply live exposed, lying on the sea bottom. Most of them avoid the light, or at least strong light.

Their food is as varied as their habits. Many live on such small animals as they are able to capture, especially mollusks and annelids, but some are plankton feeders, others simply swallow mud charged with organic material, and a few types are external parasites on coelenterates, bryozoans, crinoids and echinoids.

In nearly all Ophiurams the sexes are separate, and in a few the males and females differ; but some are hermaphroditic and viviparous. In a few types the life history includes reproduction by fission in the postlarval stage.

The podia which protude from between the lateral arm plates on the ventral side of the arms are used for breathing and very seldom for walking.

The Ophiuroidea have a distinctly different type of locomotion from their near relative the Asteroidea which move along by the use of their tube feet. The motion of the Ophiuroidea has been studied in many genera especially in

those which live on hard bottoms. All five of the arms are not utilized in walking; one—any of the five—is either pushed ahead or dragged behind while the other four are moved ahead of the disk in pairs. The ends of these four arms attach themselves and the animal draws itself forward by a jerky motion. Sometimes only the two adjacent arms are moved forward and they are used to pull the body ahead. In this way they are able to move fairly rapidly in any direction.

This position for movement has been used to interpret the attitude of a fossil Ophiuran from the Triassic. F. Klinghardt has attributed this attitude of *Ophioderma squamosum*[9] from the Lower Muschelkalk as having been in motion when killed. I think, however, that this position is due more probably to the action of water currents, such as waves, on the dead animal and does not prove that it was killed while in motion and immediately covered up by sediments.

Ophiurans choose different types of bottoms to live on. Some like a hard bottom on which they can move relatively fast and where they can find protection during the day, between and under the stones. Other types, of which *Amphioplus obditus* is an example, live buried in the mud with the ends of the arms projecting into the water.

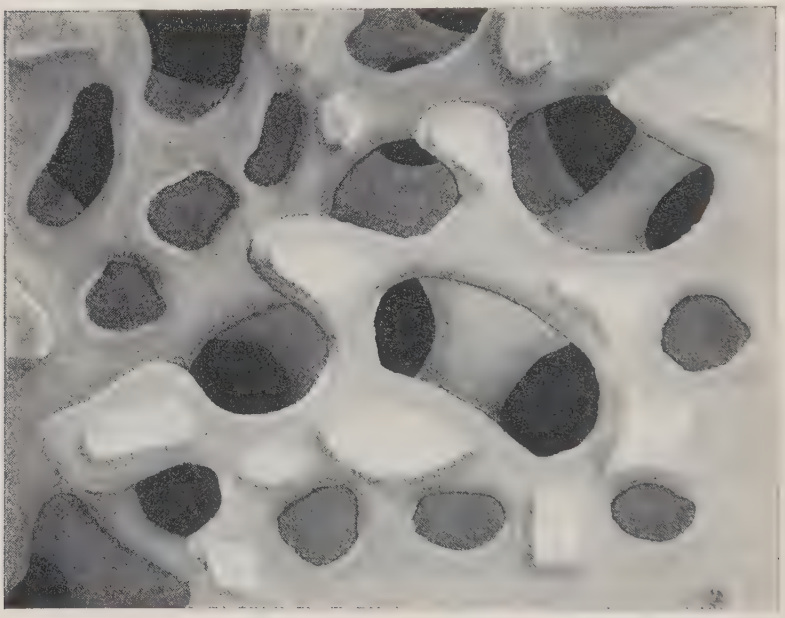
The microscopic structure of the separate plates is very interesting.

The accompanying drawing is of a section of one of the fossil radial shields cut parallel to the surface.

Under high power the plate appears to have a very reticulate structure (t. f. 1), of which each layer is about .008 mm. thick. All the elements of the structure are oriented in the same direction and give a good uniaxial figure. The material is optically negative and its indices are those found in

[9] Klinghardt, F., Über fossile und lebende Schlangensterne nebst Bemerkungen über eine Schlangenstern und Seelilien-Brehzie. Zeit. d. Deut. Geol. Ges., Bd. 82, p. 711, 1930.

calcite. When one of the plates is put in dilute acid, it effervesces readily. All this evidence points to the fact that the plates are made up of calcite. At times, however, the plates have a brownish tint which is due to a small amount of iron which they contain, coming presumably from the ground



Drawn by Clyde M. Friz

FIG. 1. Section showing the reticulate structure of a plate of *Ophiura marylandica.* Enlarged about 381 times.

water which, in certain instances, has cemented the different plates together.

In t. f. 2 I have reproduced after Schöndorf, two views —adoral and aboral—of a vertebral ossicle of *Onychaster flexilis,* of Lower Carboniferous age. On these two views the knobs and sockets can easily be seen as well as the suture which runs vertically down the center of the plate. These knobs and sockets are much more widely spaced than is the case in the living animals. This must have necessitated

a very limited amount of horizontal movement of the arms. This rigidity of the arms is to be expected if we accept the view that the Ophiuroidea were derived from the Auluroidea, which in turn came from the Asteroidea. Compare the movements of the recent Asteroid's arms with those of the living Ophiuroid's; and it is seen that the arms of the Asteroidea are very limited in horizontal movement while those of the

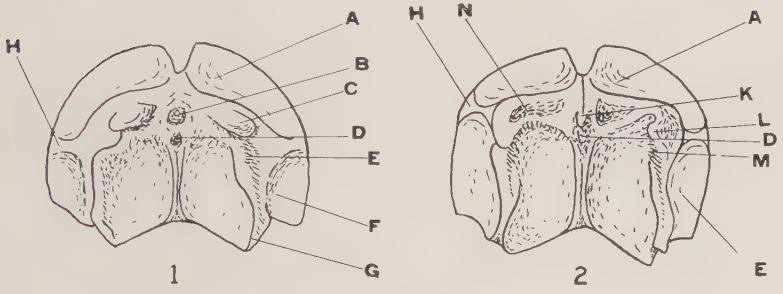


FIG. 2. *Onychaster flexilis.* After Schöndorf. No. 1, the adoral side of vertebral ossicle. No. 2, the aboral side of vertebral ossicle. A, field for upper intermediary vertebral muscle; B, unpaired median articular socket; C, depression for knob; D, median unpaired depression; E, lateral articular knob; F, field for lower intermediary vertebral muscle; G, ventral projection of the lateral knob; H, barrier separating the upper and lower intermediary vertebral muscles; K, unpaired median articular knob; L, upper lateral articular knob; M, socket for knob of adoral side; N, small depression for knob.

Ophiuroidea can move very freely, in fact, in some species they can wrap their arms about very small objects. It is therefore, with widely separated points of articulation that we find the first Ophiuroidea. Today these points of articulation have moved inward towards the center of the plate as can be seen in t. f. 3 of *Ophiura sarsii,* thus giving freer movement. It is interesting to note that in most of the fossil specimens of *Onychaster flexilis* found, the arms are curled under the animal like a bird claw, but with slight evidence of horizontal movement.

The suture which appears very pronounced in this Paleozoic Ophiuroid decreased in prominence through the ages until in some of the recent species it is hardly observable. As I have stated elsewhere it can be seen in my Miocene species. The upper and lower canal furrows can be seen in *Onychaster flexilis* as in present day species.

Schuchert makes this statement [10] which he has taken in turn from Schöndorf. "*Onychaster flexilis* shows plainly in

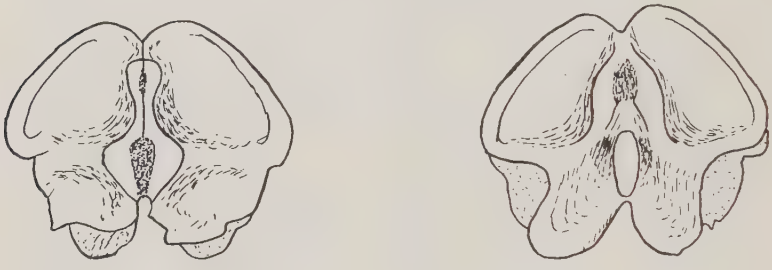


FIG. 3. Adoral and aboral views of vertebral ossicle of *Ophiura sarsii*. Enlarged 8x.

the structure of its arm-ossicles that it belongs to the Ophiuroidea. As in this subclass so also in Onychaster . . . ." In these Paleozoic Ophiuroidea the encasing plates were not as separated from the ossicle as in the present day or Tertiary species.

An interesting and valuable study could be made of the change and evolution of the vertebral ossicles throughout geologic time if enough material could be had. At present, however, there is a great lack of workable material at the disposal of the paleontologist. If one could work out and see when different types of vertebral ossicles appeared and trace them, I am sure that an objective phylogeny could be built up.

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[10] Schuchert, C., U. S. Nat. Mus., Bull. 88, p. 269, 1915. Schöndorf, op. cit., pp. 60-61.

It is hard to trace the development of the Ophiuroidea through geological ages, because the fossil specimens have been described in the works of different authors. There is therefore, a mass of literature composed of short descriptions, all from different viewpoints; making it impossible to correctly correlate the results. However, the fossil genera and species seem to have increased during the Triassic, reaching their maximum in the Jurassic and then declining during the Cretaceous. I am sure that this is due, to a great extent, to the fact that in the Jurassic and Triassic times the conditions were more favorable for preservation of these delicate animals. Many of the specimens of this time are from Germany and were found in such beds as those at Solenhofen, where the sediments were extremely fine. There is a pronounced decline in the number of genera and species from the Cretaceous throughout the Tertiary to 18 genera and 4 species in the Miocene.

At the opening of the Tertiary period, in Eocene time, there are only two known genera, and the like number of species. The one *Ophiura wetherelli* was found in the London Clay at Hampstead, England; while the other *Ophiurites eocaenus* comes from the Middle Eocene of Belgium. Remains have been found in the Byram Calcareous Marl (Oligocene) from Byram Ferry, Mississippi; while the Miocene seems to have produced more than any of the other epochs of the Tertiary period. Those found which lived during Miocene times are dealt with elsewhere in more detail. The Pliocene seems to have been devoid of these animals for I have found none mentioned in the literature, even though I represented some in t. f. 4 as having been found at this time. During Pleistocene times more Ophiuroidea seemed to have been preserved for something like nine species in five or more genera have been reported. Several fragments of

Ophiurans have been found from the Pleistocene of Venezuela and Trinidad, but have not as yet been described.

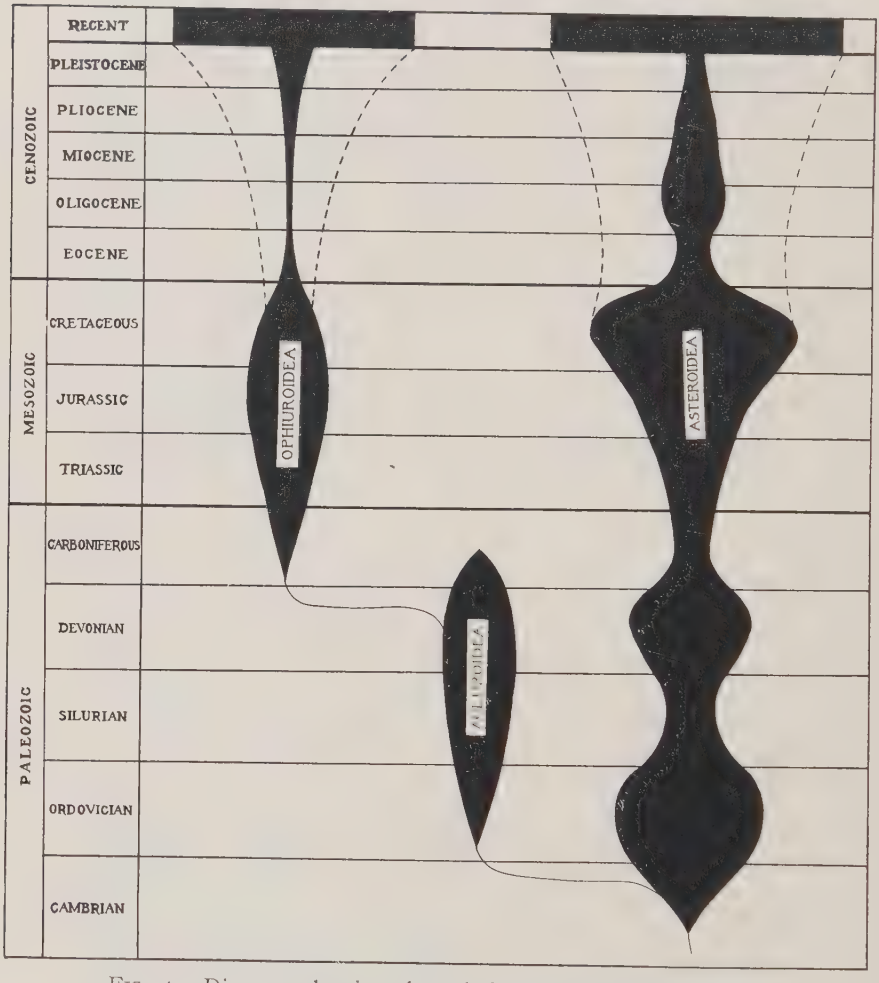

FIG. 4. Diagram showing the relationship, abundance, and geological history of the Ophiuroidea, the Auluroidea, and the Asteroidea.

Leaving the fossil Ophiuroidea we find in our present oceans something like 189 genera and 1,412 species. Can it be possible that from the few animals that were apparently

living at the close of the Tertiary period, such a great number could be evolved in such a short time? I think not! I think that there are many gaps in our fossil collections which can never be filled and there are others which will be filled by future collecting and by work on those which are already in our Museums, but which have been neglected to date. Much of the deposition of Tertiary times was not indusive to the preservation of such delicate animals. It is for this reason that I have outlined by dashed lines in Figure 4 what I think must have been the increase in numbers of species during Tertiary times. The solid black area represents those species actually found fossil.

It is interesting to note that most all of the fossil Ophiurans are much smaller in size than the majority of living forms. Of course, there are many very small individuals living in the present day seas, but the majority of the species are large. Can their size and their great abundance in the present day oceans be ascribed to the fact that this subclass has just reached its zenith in individual size and diversification in development?

The Ophiurans, however, did not assume their diagnostic characters as a distance subclass until during the Carboniferous, thus it is quite probable that they are at present at their summit of development. I think that this fact is most likely true even when the factor of the unlikelyhood of preservation and our lack of knowledge of the animals during the Tertiary is taken into consideration. Thus this is one explanation for the contrast between the number of Tertiary forms and the great diffusion of these animals in our present seas.

SURVEY OF THE MIOCENE OPHIUROIDEA

In working over the literature on Tertiary fossil Ophiuroidea I found that very few species had been described from formations of Miocene age. The few that have been are from various localities. Of these, three have been described from the United States, one from California and the others from Maryland. I will deal with the one from California first and then take up those nearer home.

In 1908 R. Arnold [11] described an Ophiuroid from the Santa Margarita formation (Upper Miocene) of Santa Cruz County, six miles north-northeast of Santa Cruz, California. He placed this in the genus Amphiura and took the locality as the specific name—*sanctaecrucis*. This new species was based on two specimens of, "beautifully preserved molds," one showing the dorsal side clearly while the other showed the ventral side; which, however, is a little indistinct in places. The one showing the dorsal side was taken for the type; and it is now in the Stanford University, Geological Collection. Arnold gives the dimension for these two specimens as follows: [12]—"Specimen exhibiting dorsal surface diameter of disk 13 mm.; arms at least 25 mm. long and probably several times this amount; width near disk 2 mm.; upper arm plates 0.7 to 0.8 mm. long. Specimen exhibiting ventral surface; diameter of disk 6.5 mm.; arm at 20 mm. long and probably at least twice this length judging by taper." The specimens were found by W. J. Miller in the soft arenaceous shale immediately overlying the Santa Margarita sandstone in Santa Cruz County, California.

Recently C. W. Merriam [13] and T. D. Bailey have discovered a California limestone composed chiefly of Ophiuroidea

[11] Arnold, R., Description of a New Brittle Star from the Upper Miocene of the Santa Cruz Mts., California. Proc. U. S. Nat. Mus., Vol. xxxiv, pp. 403-406, 1908.

[12] Arnold, R., op. cit., p. 404.

[13] Merriam, C. W., Notes on a Brittle-Star Limestone from the Miocene of California. Amer. Jour. Sci., Vol. 21, ser. 5, p. 304, 1913.

remains. This lens of limestone according to Merriam is about a foot thick and sixty feet long outcropping along the strike of the east limb of what appears to be a broad syncline which runs across Nipomo Quadrangle in a southeast-northwest direction. This limestone occurs in the Santa Margarita formation (Upper Miocene), the same from which Arnold described *Amphiura sanctaecrucis*.[14] On the weathered surface of this limestone there appear many interwoven arms and a few indistinct disks of Ophiurans, but none perfect enough to be clearly identified. Merriam is of the opinion that they can be studied by a carefully prepared series of slides showing the vertebral ossicles. However, he has not identified any of the Ophiurans found in this limestone in his paper.

It is interesting to note that the Miocene Ophiuroidea reported from California are from the same formation:— Santa Margarita. It is most likely that the species are identical even though Merriam only hints at such a relationship. Undescribed Ophiuran remains have been found in the Upper Miocene of California at several other localities: San Pablo, Upper Miocene of Contro Costa County, and also at Granerros Creek, four miles west of Napa, California. These might or might not belong to the same species that Arnold described in 1908.[15]

Leaving California and coming to the Atlantic coast we find that in the literature there is one reference to a fossil Ophiuran of Miocene age and that this specimen was found in Maryland.

A fragment of the arm of an Ophiuroid was found in the indurated ledge along the St. Mary's River, Maryland. This indurated ledge is in the St. Mary's formation. The specimen consisted of a portion of an arm found inside a large gastropod shell. These fragments were given the generic

[14] Arnold, R., op. cit., pp. 403-406.

[15] Arnold, R., op. cit., pp. 403-406.

name of Ophioderma, but no specific name. The incomplete description of this Ophioderma first appeared in the Maryland Miocene Report[16] and then was repeated in 1915 by W. B. Clark[17] in the same form in which it had earlier appeared. The specimen is supposed to be in the Johns Hopkins University Geological Collections, but after several futile searches I have decided that it is lost. I think that if I could find the specimen again it might prove to be the same as *Ophiura marylandica* on which this work is based. They are of the same geological age and are very closely approximated geographically; even if the exact location of the first discovered Ophiuroidea's remains in Maryland is not known.

This and the new species *Ophiura marylandica* are the only two Ophiuroid remains of Miocene age that have been found along the Atlantic coast. There may be other accounts which I have not come across, but I hardly think so.

Leaving the North American continent we find:—S. T. Hall[18] has recorded and figured one vertebral ossicle from the Miocene of Victoria. This lone ossicle has been compared with those of *Sigsbeia* which it somewhat resembles. From the figures, the ossicle appears to be very badly worn and poorly preserved, so much so that no distinct characters stand out. This is the only specimen of Ophiuroid found in Australia. The specimen's location is given as Grange Burn ("Forsyth's"), near Hamilton; and is of Kalimnan (Miocene) age.

Turning now to Poland the Ophiuran which has been named *Ephippiellum symmetricum* is of Miocene age. The name is given not to a complete animal, but to fragments. As the article is in Polish I am unable to discuss it.

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[16] Maryland Geological Survey, Miocene Report, p. 433, 1904.

[17] Clark, W. B., Mesozoic and Cenozoic Echinodermata of the United States. Mon. U. S. Geol. Surv., Vol. liv, p. 178, 1915.

[18] Hall, S. T., New or Little Known Fossils from the Tertiaries of Victoria. Proc. Roy. Soc. Victoria (new ser.), Vol. xv, pt. 1, p. 82, 1902.

EARLY HISTORY OF FOSSIL OPHIUROIDEA

The earliest description of a fossil Ophiuroid that I have found, is one by Blumenbach in 1804.[19] It was at that time called *Asterites scutellatus* and came from beds of Triassic age, but it was reclassified as *Aspidura loricata* by Boehm in 1889.[20] The next reference to a fossil Ophiuroid was twenty years later than Blumenbach when Konig [21] described *Ophiura libanotica* from beds of Cretaceous age. This was reclassified by Boehm [22] and named *Geocoma libanotica*. From this time on descriptions appeared until the beginning of the twentieth century when for some unapparent reason scientists seem to have grown tired of working on the fossil Ophiuroidea, for since 1900 very little work has been done.

EARLY HISTORY OF RECENT OPHIUROIDEA

These little five-armed animals attracted the attention of the earliest scientists over two hundred years ago, for it was in 1733 that Linck [23] described two species. These he named *Stella lacertosa* and *Stella longicauda* because of their close resemblance to the tails of lizards. Linck described other species and he seems to have done quite an extensive piece of work on the Ophiuroidea (as called today) during his lifetime. Many scientists, among whom we have Seba, Pennant, O. F. Muller, and Linné, have worked on these animals, but it was not until 1816 that Lamarck,[24] the noted French scientist, established the generic name Ophiura. Lamarck took as a type for this genus that specimen which

[19] Blumenback, Specimen archaeologiae telluris, etc. Commentationes societatis regiae scientiarum gottingensis, classic phusocae, Bd. xv, p. 153, T. II, F. 10, 1804.

[20] Boehm, G., Ein Beitrag sur Kenntniss fossiler Ophiuren, Berichte der nat. Ges. z. Freiberg, Bd. I, Vol. iv, p. 256, 1889.

[21] Konig, Icones fossilium sectiles, T. II, F. 26, 1825.

[22] Boehm, G., op. cit., p. 268.

[23] Linck, De Stellis Marinis, fol. 1733.

[24] Lamarck, Systeme des Animaux sans Vertebris 2, p. 540, 1816.

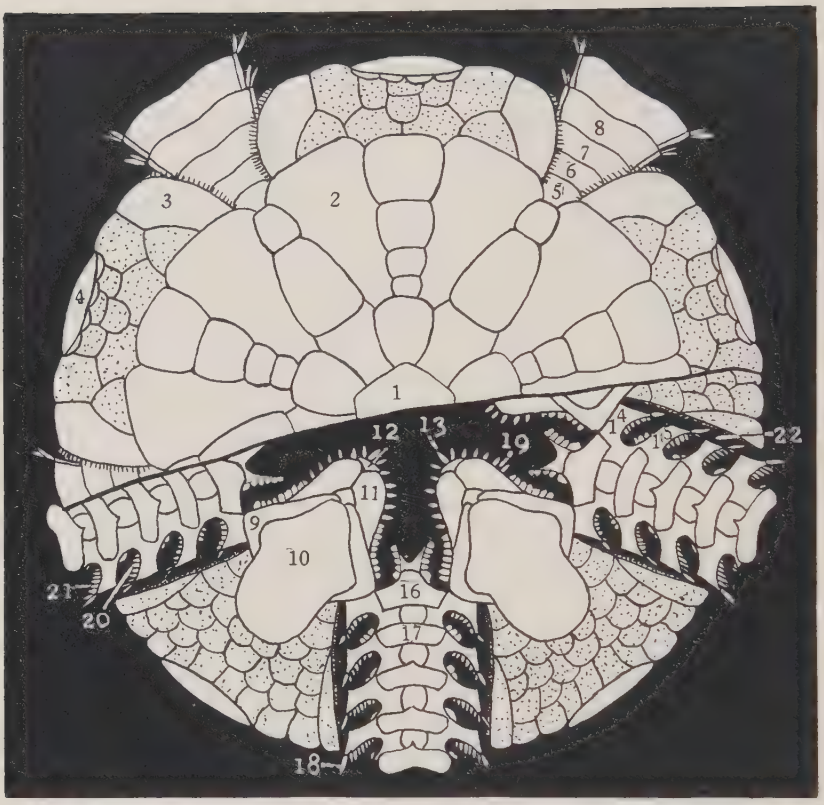

FIG. 5. Reconstructed *Ophiura marylandica*. The upper half of the figure shows the dorsal side, while the lower half shows the ventral side. The stippled plates are hypothetical. 1, Central disk plate. 2, Radial shield. 3, Comb plate. 4, Interradial marginal plate. 5, First dorsal arm plate. 6, Second dorsal arm plate. 7, Third dorsal arm plate. 8, Fourth dorsal arm plate. 9, Side mouth shield. 10, Oral shield. 11, Jaw. 12, Torus angularis. 13, Teeth. 14, First lateral arm plate. 15, Second lateral arm plate. 16, First ventral arm plate. 17, Second ventral arm plate. 18, Spine. 19, Mouth papillae. 20, Tentacle pore. 21, Tentacle scales. 22, Genital slit.

Muller had earlier called *Asterias ophiura* and renamed it —*Ophiura texturata*. However, Lamarck's generic distinction lasted less than twenty-five years, for it was in 1835 that Agassiz [25] proposed a new generic subdivision of the order. This genus is one of the largest found living in the present oceans.

DIAGNOSIS OF OPHIURA MARYLANDICA

The diameter of the disk ranged from 10 to 15 mm. with very pronounced radial shields on the dorsal side, a five-sided central disk plate, and large comb plates flanking the base of each arm. On the ventral side of the disk the flattened arrow headed oral shields were pronounced. Between the base of the arms on the margin of the disk are situated the large interradial marginal plates. The arms, which are five in number, are composed of approximately 45 to 60 segments, being long and tapering they are about 45 to 60 mm. long. Each segment of the arm is made up of one dorsal arm plate, two lateral arm plates, which, near the base of the arm, do not unite on the ventral side, as in some species, and a small ventral arm plate, all of which encloses a vertebral ossicle.

Since the future recognition of the species depends upon detailed comparison of individual plates, a specific diagnosis at this point would be scarcely intelligible and certainly not a usable summary of the complete description of the plates which follows. Consequently no such summary is attempted.

LOCATION OF PLATES

For the sake of brevity and conciseness I think it would be best to name the different kinds of plates and give their location—in reference to each other and the rest of the animal—at this point, in order to save repetition later in the

[25] Agassiz., Mem. Soc. Sci. Nat. Neuchatel, Vol. 1, p. 168, 1835.

description of the separate plates belonging to the three separate species.

Taking the upper or dorsal side we have the following plates of importance which are discussed in this paper:—

CENTRAL DISK PLATE

Text Fig. 5—No. 1

This rounded to polygon-shaped plate is situated in the center of the disk, overlapping in most cases the plates which surround it. When this plate is present it acts as the center of the radial symmetry of the animal.

RADIAL SHIELDS

Text Fig. 5—No. 2

These plates are located in pairs, one on each side at the base of the arm and they are in contact distally, with their apex adoral. In some species these plates are very prominent while in others they are almost totally lacking, taking different shapes according to their prominence.

COMB PLATE

Text Fig. 5—No. 3

One comb plate flanks each side of the base of the arm. These plates adjoin and lie aborally to the radial shields and only flank the dorsal half of the arm. The comb plates cover varying proportions of the limbs of the third, fourth and fifth dorsal arm plates. As will be stated more fully elsewhere these comb plates are not present in all genera. It is on these plates that the small papillae, which are used for classification, appear.

INTERRADIAL MARGINAL PLATE

Text Fig. 5—No. 4

One of these plates lies interradially, with its longest axis horizontal, between each arm, on the lateral margin of the

disk. This plate is of varying size, sometimes being totally lacking in some species.

DORSAL ARM PLATES

The dorsal arm plates are those plates which are located on the dorsal side of the arm. They lie directly above the vertebral ossicles and unite with the dorsal ends of the lateral arm plates. These dorsal arm plates are either articulated to each other by teeth and sockets or by a strong muscular attachment. The first four or five dorsal arm plates are distinctively different from the rest of the dorsal arm plates and are described separately.

FIRST DORSAL ARM PLATE

Text Fig. 5—No. 5

The first dorsal arm plate is the first of a series of plates which appear on the dorsal side of the arm. It is located between the base of the radial shields.

SECOND DORSAL ARM PLATE

Text Fig. 5—No. 6

This plate follows the first dorsal arm plate and is partly overlapped by the radial shields.

THIRD DORSAL ARM PLATE

Text Fig. 5—No. 7

This plate is the third one in the series on the dorsal side of the arm from the disk. Its lower limbs are overlapped by the comb plate.

FOURTH DORSAL ARM PLATE

Text Fig. 5—No. 8

The fourth dorsal arm plate is the last in most cases, of the series of plates which are distinctive from the rest of the dorsal arm plates. This plate is partly overlapped by the

comb plate. In some species there appears beside this fourth dorsal arm plate another distinctive plate, the fifth dorsal arm plate. In this latter case it is also partly overlapped by the comb plates.

Now viewing the animal from the ventral side the following outstanding plates can be seen:

SIDE MOUTH SHIELD

Text Fig. 5—No. 9

Two of these plates, one on each limb, flank the proximal angle of the oral shield. They are mostly covered by the oral shield, lying or bordering the mouth of the animal. The dorsal end of the apophysis is in contact with the genital plate (Fig. 9 D) while its aboral edge is in contact with the first lateral arm plate.

ORAL SHIELD

Text Fig. 5—No. 10

The oral shield is placed interradially near the center of the disk. Its pointed end is adorally placed. This plate is the most prominent one on the ventral side of the animal.

JAW

Text Fig. 5—No. 11

The jaw, as a whole, consists of two parts which are situated at the adoral end of the vertebral column. These two halves are loosely articulated to the first vertebral ossicle, in much the same way as the separate ossicles are articulated to each other. The adoral end of each half of the jaw is in contact with that of the neighboring jaw, interradially, and is partly held together by the torus angularis. These jaw plates are mostly enclosed within the body cavity (disk) of the animal leaving only the interradial apex exposed on the ventral side of the disk.

TORUS ANGULARSIS

Text Fig. 5—No. 12

This plate is located at the intersection of the two jaw plates at their adoral end. It is to this plate that the teeth are attached.

TEETH

Text Fig. 5—No. 13

The teeth are situated on the torus angularis, all pointing in towards the center of the mouth.

LATERAL ARM PLATES

The lateral arm plates are those plates which enclose the vertebral ossicle on the sides. The dorsal end of these plates is in contact with the dorsal arm plates while the ventral ends are either in contact with each other or are separated by a space. This space is partly filled with the ventral arm plates. The first, second, and third lateral arm plates are somewhat different from the rest, so they will be described separately.

FIRST LATERAL ARM PLATE

Text Fig. 5—No. 14

The first lateral arm plate is the first of the lateral arm plates at the base of the arm. Almost all of the plate is enclosed within the disk, leaving only about one-third exposed on the ventral side of the animal. The dorsal edge of the aboral end of the plate is in close contact with the genital plate (Fig. 9 E). The plate abuts the second lateral arm plate on the aboral side. The median edges of these plates are sometimes in contact with each other and at other times they are not.

SECOND LATERAL ARM PLATE

Text Fig. 5—No. 15

The second lateral arm plate is situated just aborally of the first. However, less of it comes in contact with the genital

plate (Fig. 9 F). The third lateral arm plate is just behind the second and is similarly situated to the preceding two.

VENTRAL ARM PLATES

The ventral arm plates lie on the ventral side of the arm, adoral of each arm segment. They are not, however, in contact with each succeeding plate, but are placed separately; being abutted by the lateral arm plates.

FIRST VENTRAL ARM PLATE

Text Fig. 5—No. 16

This plate is the first in the series of the ventral arm plates which are arranged on the ventral side of the arm. It is similarly in contact with the other plates, like all the rest of the ventral arm plates.

GENITAL PLATE

Text Fig. 9 H

The genital plates are not exposed on the surface of the animal, but lie internally. There is one on each side of the row of vertebral ossicles, lying parallel to the axis of the arm. They slant downward, the aboral end being near the dorsal surface of the disk and attached to the comb plate. The adoral end is much lower and in juxtaposition with the first lateral arm plate.

VERTEBRAL OSSICLES

The vertebral ossicles are the central plates in the arm of the animal, thus lying wholly inside of the outer plates. Each vertebral ossicle is surrounded by a dorsal and ventral arm plate and two lateral arm plates. The ossicles are articulated to each other by means of sockets and condyles. In describing the vertebral ossicles I have followed as nearly as possible the terminology proposed by H. L. Clark in 1914.[26]

[26] Clark, H. L., Growth Changes in Brittle-Stars, Carnegie Inst. Washington, publication. Vol. 5, pp. 99-126, 1914.

FIRST VERTEBRAL OSSICLE

Text Fig. 9 L

This ossicle is the first vertebral ossicle and is articulated on its adoral side to the jaw.

NOTE:—Throughout the paper the terms, right and left, are used to designate those corresponding sides which are seen while looking towards the center of the disk; either from the dorsal or ventral portion of the animal.

Class OPHIUROIDEA

Order CHILOPHIURIDA MATSUMOTO

Family Ophiolepididae Ljungman

Subfamily Ophiomastinae Matsumoto

Genus Ophiura (Lamarck)

Ophiura marylandica n. sp. C. Berry

CENTRAL DISK PLATE

PLATE I—Fig. 12

The plate which I have called the central disk plate is nearly a true polygon. All the angles are equal and the sides are straight except for one side which is concaved. This concaved side appears to have been broken, instead of having grown irregularly, for the edges of the plate are extremely thin. One surface of the plate is flat, and this is I think the external surface, while the other side is swollen. This supposed internal side shows evidence of overlapping the adjoining plates.

The plate has an internal diameter of 1.12 mm. and an external diameter of 1.34 mm. Very few perfect specimens of this plate were found.

This plate appears in the center of the dorsal side of the disk of several living species and has been found in the young stages when the disk was less than 2 mm. in diameter. Each side of the polygon is interradially placed. Since the central plate is five-sided it is concluded that the animal had

five arms. This conclusion is confirmed by the symmetry that is found in most of the living species, which have a five-sided central disk plate and five arms.

RADIAL SHIELD

PLATE I—Figs. 7, 8

The radial shield is roughly a right angle scalene triangle being longer than broad. The external surface of the plate is smooth and slightly swollen in some of the specimens. The older plates are bevelled on their two longest margins. This could not be observed on the youngest (smallest) plates at all. This bevelling shows that the edges of the shields were overlapped by other plates. This overlapping has been observed where pieces of the fossil disk were found intact. The right angle of the triangle has been truncated and in the space thus left the first dorsal arm plate is located. The inner surface is smooth except for a swelling in the corner opposite the longest side. This condyle acts as a point of articulation.

The plate which I choose for the type is 3.38 mm. long, and 2.24 mm. wide, and .56 mm. thick. The radial shields as can be judged are large and preserved in abundance; many, however, being broken.

COMB PLATE

PLATE I—Figs. 6, 9

The general shape of the comb plate is that of a trapezium whose shortest axis is strongly arched and along the longest axis the plate is half twisted. The longest side of the plate adjoins the arm, the next shortest margin is away from the arm, the next shortest margin is dorsally placed. The external surface is smoothly curved, with the ventral third of the surface slightly depressed, showing that it was overlapped by other plates, leaving only about two-thirds of the surface exposed.

Along the inner or longest margin there is a row of small sockets about 12 in number into which the comb papillae fit. The ventral or next to the smallest margin is rounded and very thin—this is the margin that is covered by other plates. The dorsal or smallest margin is concaved and forms an acute angle with the longest margin.

The internal surface (Plate I, Fig. 9) is similar to the external, except that it is concave. It is elevated in the center of the plate thus making it much thicker here than near the periphery. The dorsal or shortest margin is better exposed on the internal surface and the articular surface can be seen. The margin increases in width from the acute angle it makes with the longest side to a point where it swells out and forms a pronounced socket.

The comb plate is large and thick and many were preserved. Of course some of the thin edges were broken off in many specimens, but the majority were perfect. The plates vary in size from 2.84 to .68 mm. in length and from 1.48 mm. to .40 mm. in width.

DORSAL ARM PLATES

PLATE I—Figs. 1, 16

The plates on the dorsal side of the arms of Ophiurans show a gradation from an adult stage, at the base of the arm; to those which terminate the arm, the youngest. For this reason no two of the plates from the same arm are exactly alike. There is also a very great difference between the first four dorsal plates and all of the rest. I will describe them separately, dealing now with the other dorsal plates and enumerating what changes take place in their development.

The older plates have a general shape of a spherical equilateral trapezoid, much wider than long. The typical one that I have selected for this type has a very arched transverse axis while longitudinally it is only slightly convex. Just a little aboral to the adoral margin, on the outer surface, in

the axis of the plate are three small teeth, the middle one (primary) being more pronounced than the other two (secondary). The aboral margin of the plate is smooth and equilaterally sinuate with a wide medium sinus and flat rounded lobes. The plate, which is thick, is smooth on the internal side except for three sockets which are located about one-third the way from the aboral margin on the axis of the plate. This shows that the plates overlap each other and that the segments near the base of the arm are not as flexible as those farther out.

In the next pronounced younger stage the plates are not as wide and are longer, giving them nearly equal proportions. These are less arched and are only very slightly convex longitudinally. The adoral margin which is nearly straight has the three teeth extending beyond it. These teeth are usually placed close together, but on one plate the secondary teeth were not as close to the primary tooth, but separated by a little distance. As I found this difference on only one plate, it can be attributed to some pathological growth instead of to a distinct species. The aboral margin is gently curved. On the inner side of the plate the sockets are still adoral of the aboral margin, showing that they still overlap a little.

In a still younger stage the length of the plate has increased with a shortening of the adoral margin. Upon this adoral margin is only the primary tooth, the two secondary teeth not having appeared, as seen on the older plates. The socket on the internal side of the plate are very primary in development.

On the youngest plate that I found there were no teeth developed. It was spatulate in shape, practically flat, much longer than broad; with a very narrow straight adoral margin and a pronounced convexly curved aboral margin.

The first four dorsal arm plates as I have already stated are distinctly different from any of the other arm plates. This difference is due to the crowding and overlapping of the

radial shields and comb plates, which adjoin the dorsal arm plates in this region.

Each segment of the arm consists of four external plates and the internal vertebral. The external plates are:—two lateral plates, one dorsal and an intersegmental ventral plate which lies adoral of each segment. The vertebral is composed of a fusion of two lateral plates lying side by side. In a few vertebral ossicle evidence of this has been clearly seen by a crack or parting running longitudinally through the plate.

The sequence in the development of the dorsal arm plates has been brought out by arranging (Plate I, Fig. 1) 34 plates of graduate size into a hypothical arm. The average arm of a recent ophiuran consists of about 40 segments. There is of course a great chance for error to enter in when building up such a hypothetical arm, but it is a good illustration of the way in which the plates vary and it was only after studying many recent specimens that I ventured to construct such an arm from my fossil plates. In several cases I found two or more segments cemented together by iron solution upon which, part of this reconstruction of the dorsal arm plates was based. There is of course the additional factor that these plates came from animals of many different ages, but this is neutralized by Jackson's law of "Localized stages." This law which has been applied in the study of recent ophiurans in many cases is briefly this:—"the ophiuran arm reveals at and near the tip the characters of youth and one can thus compare the base of the arm of a small specimen with the middle or tip of the arm of a large individual." [27] With a very few minor variations this arrangement of dorsal arm plates should therefore be correct.

The first four dorsal arm plates show the marked difference in the configuration on the lateral sides and the external surface, from the rest of the plates. The shortening of the breath with the lengthening of the plates in the decreasing

[27] Clark, H. L., U. S. Nat. Mus. Bull., 75, p. 3, 1911.

of size of the younger plates is illustrated. In all cases where possible these plates bearing teeth were used, and it is regrettable that the sequence in the growth of the teeth could not be fully illustrated on the 34 plates.

FIRST DORSAL ARM PLATE

PLATE I, Fig. 1

The first dorsal arm plate is a little nondescript wedge-shaped plate, and is easily overlooked unless special attention is directed towards it. The adoral surface forms the acute edge of the wedge, the edge, however, slants towards the external surface aborally. The external surface is full and evenly rounded without any outstanding markings upon it. The aboral side is slightly hollowed transversely and slants parallel to the adoral side. The internal surface is flat and cordate, the apex being adoral.

There is a great probability that its shape is governed by the growth of the radial shields, yet all the fossil ones found were practically identical in general shape; but varied in size. Since these plates are very small and indistinct, only a few were found.

SECOND DORSAL ARM PLATE

PLATE I—Figs. 1, 19

The second dorsal arm plate has the general shape of a modified rectangular parallelepiped, its thickness being the greatest dimension, while it is broader than long. The external surface of the plate is an equilateral trapezoid with the smaller parallel side adoral. The general surface is inclined adorally, but is greatly swollen giving a dome-like appearance and leaving a narrow flat margin on the two lateral sides and the adoral side. It is along these two lateral edges that in the recent species are found small pallae. The adoral margin is slightly excavated while the aboral edge is straight.

The internal surface of the plate is much broader than the external, due to the flaring of the two lateral sides. The aboral margin is notched axially. The lateral margins are equilaterally rounded into the adoral margin. The surface is, however, slightly concave.

Each lateral side is a rhombus, the aboral margin of which is slightly concaved. The surface flares near the internal margin.

The aboral surface is a concaved equilateral trapezoid with its lateral and internal margins concaved, while its external margin is convexed.

The adoral surface is a small flat equilateral trapezoid which is grooved axially on the internal margin.

These plates, which are very minute, as can be seen from the illustrations, were very scarce and only a limited number were found. The type one is .78 mm. across adorally, .62 mm. long, and .84 mm. thick adorally.

THIRD DORSAL ARM PLATE

PLATE I—Figs. 1, 20

The third dorsal arm plate is more or less an enlargement of the second dorsal arm plate. It is, however, much broader and thicker, but only a little longer. The external surface is an equilateral trapezoid, similar to plate two; but more swollen. The general shape of the surface is the continuation of that which appears in the preceding plate. The internal surface differs from that of Plate 2 by being more concaved. The surface slopes aborally towards the external side.

Each of the lateral sides are rhomboids with a concaved aboral margin. The aboral side which forms an arch across the aboral end of the plate is very narrow and regressive. There are, however, two small and indistinct sockets on the axis. The adoral surface is an equilateral trapezoid on which there is a single small axial tooth, which runs vertically across nearly the entire surface.

The type specimen is .62 mm. across the adoral margin, .56 mm. long, and .73 mm. thick along the adoral margin in the center.

FOURTH DORSAL ARM PLATE

PLATE I—Figs. 1, 21

The fourth dorsal arm plate is very similar to the third, but it is, however, the broadest of any of the dorsal arm plates. It has about the same thickness and length as the preceding plate.

The external surface is, however, strongly arched aborally, more so than in the third plate. The aboral margin of the plate is smooth and equilaterally sinuate with a wide median sinus and rounded lobes, whose outer extremities plunge downward to form the lateral sides. The adoral margin of the plate is equilaterally sinuate with two shallow sinuses and rounded lobes. On the axial lobe are two faint teeth, which, however, in many cases are either entirely worn off or nearly so, thus making them very indistinct. The lateral sides which were vertical or nearly so in the second and third dorsal arm plates have now flattened out, still retaining their raised surface, so as to form the limbs of the arched exterior surface of the plate. The remnant of the lateral sides, which are well developed in plates 2 and 3, is shown by the edge of the raised surface, which starts about one-quarter the distance in from the lateral margin on the adoral margin. This edge runs in a straight diagonal line towards the lateral margin and joins the ends of the rounded lobes of the aboral margin. These two remnants of the lateral surface converge adorally.

The internal surface is smoothly concaved and slopes aborally towards the external side, which in itself is only a narrow groove which bears three very faint indistinct sockets axially. There really is no distinct adoral surface for the external surface rounds down to the internal surface, giving no distinct marking except the adoral ridge which marks the

adoral edge of the old lateral side. There are two faint teeth which run vertically in the axial plane of the plate.

The type plate is .84 mm. across the adoral margin, .67 mm. thick on the adoral margin and .62 mm. long. I found that it was very hard to distinguish between the second, third, and fourth dorsal arm plates unless there were a great number of plates to work with.

INTERRADIAL MARGINAL PLATE

PLATE I—Figs. 17, 18

The general shape of the interradial marginal plate is elliptical with the ventral side flattened or at times even slightly concave. The external surface of the plate is strongly arched along the shorter axis, in order to conform with the curvature of the surface of the disk. The surface of the plate is, however, straight along the long axis except a rounding off at the ends. The internal surface is not plain, but is elevated to some extent in the center along the shorter axis. This elevation decreases towards the ends of the long axis making the plate much thinner in these regions than in the middle. Two raised areas appear on the ventral margin on the internal surface of the plate. These gently raised areas are situated about one-quarter the way in from each end, and appears to act as some kind of point of articulation. On some of the specimens found these places were more developed than on others, and on those plates where they were highly developed the concavity on the ventral margin was more pronounced. All gradations were found among the many whole plates picked out.

The size of the type plate is 2.02 mm. along the longest axis, 1.40 mm. along the shortest axis, and .45 mm. thick at the center.

These plates show no evidence of having been overlapped. On the contrary one of these marginal plates was found overlapping four much smaller plates which were clinging to the

ventral margin of the larger plate. Due to their large size these plates must have been very prominent on the fossil ophiuran.

ORAL SHIELD

PLATE I—Figs. 30, 31

The oral shield, or the buccal plate as it was formally called, has the general shape of a flattened arrow head. The plate (Plate I, Fig. 30) is very much longer than broad with a smooth slightly rounded outer surface. The sides of the broad proximal angle, or point of the arrow, makes an angle of about 90 degrees at the apex, which in itself is slightly rounded. The limbs which are somewhat concave, varying a little in different specimens, extend beyond the nearly parallel lateral margins of the plate. The ends of the limbs incurve sharply to the lateral sides, sometimes making a shallow sinus on the sides. The parallel lateral margins are either very slightly expanded or contracted towards the distal margins; but this difference is not pronounced enough to differentiate them, for these differences grade into each other. The distal margin of the plate is gently curved.

The inner surface (Plate I, Fig. 31) of the plate is uneven, due to the depressed areas where this plate overlaps the other ventral disk plates. The inner surface along the limbs of the proximal angle is deeply depressed, making the edges of the plate very thin here. Into these areas the side mouth plates fit. Along the distal margin the plate is bevelled, decreasing in amount towards the proximal end of the plate. This would prove that the outer surface of the plate was level with the other ventral disk plates. The sides of the plate would not necessarily be bevelled, for the genital openings are present here. About in the center of the plate where it is thickest there is a deep depression, this depression is more pronounced in some plates than in others. I think that some ligament or muscle must have been attached at this point.

The type plate that I have selected is 2.58 mm. over all in length, 1.79 mm. at its maximum width. These plates were very large and solid so that many were found both complete as well as broken ones. This plate in most species is the largest one to be found on the ventral side and is very conspicuous on the recent ophiurans.

SIDE MOUTH SHIELD

PLATE I—Figs. 2, 3

Only about half of the side mouth shield is exposed on the ventral side of the disk, the rest being covered by the oral shield. The part seen on the ventral surface is only a long narrow triangle; with a very acute apex and a very narrow base, about one-third of the entire width of the plate. The surface slopes away from the oral plate. The two side mouth shields meet at the apex of the proximal angle of the oral plate.

The shape of a detached individual plate (Plate I, Fig. 2) is very different from what is seen exposed on the ventral side of the disk. The plate is a trapezium with its longest diagonal radially. At the aboral end on the inside of the plate there is a large narrowly pointed apophysis. The ventral or external surface of the plate has a fold running radially, which becomes wider tangentially near the aboral end. This fold parallels the inner edge of the plate. The rest of the surface (one-half to two-thirds) is a wide, high arch which parallels the outer side and which is wider near the aboral end of the plate. Along the crest of this arch there runs a very faint groove (in some of the specimens this groove cannot be seen). This groove marks the position to which the edge of the overlapping oral shields extend. The arched ventral surface of the side mouth shield has its corresponding part in the concavities on the internal side of the oral plate.

The internal surface of the side mouth shield is uneven (Plate I, Fig. 3), being swollen near the center. This swollen

area culminates a little aboral of the center of the plate, on the longest diagonal, in a narrow, but long high apophysis which culminates in a sharp point directly above the aboral end. The end of this apophysis is attached to the adoral end of the genital plate in the groove which runs down the ventral side of that plate. This connection can be seen in Fig. 10. There is a groove, deep at the base and diminishing in intensity, which runs part of the way up this apophysis on the outer side of the projection. On the inner side of this apophysis at its base is a small projection near the inner corner of the plate. The adoral edge of the apophysis is rounded while the aboral edge is very sharp. At the aboral base of this apophysis there is on the outer side a very small, but well rounded, deep sinus. Often the end of the apophysis has been broken off so that very few perfect specimens were found.

The type specimen is 1.51 mm. radially, 1.18 mm. at its greatest tangential width, and .90 mm. from the tip of the apophysis to the external surface of the plate.

FIRST VENTRAL ARM PLATE

PLATE I—Figs. 10, 11

The first ventral arm plate is distinctly unlike the other ventral arm plates, the width being greater than the length, the proportions are about 2 to 1. The plate has a general triangular shape being, however, much modified. The aboral margin, the base of the triangle, of the plate is concave with the lateral margins flaring sharply; naturally these sides are straight, but sometimes they are concave. The adoral margin consists of two equilateral incurved sides which culminates into a truncated projection which occupies about one-third of the width of the entire adoral margin and located in the axial third of the plate. All the angles are slightly rounded and not acute.

The external surface (Plate I, Fig. 10) is rounded, mounting from a thin aboral margin to a thick adoral margin.

There is a slight groove which forms a lip that runs along the adoral margin on the external surface. This lip rises gradually from near the lateral margins and increases to its maximum on the side of the flat-ended projection, but here it is suddenly depressed at the extreme adoral point. This lip is only very pronounced on the mature specimens and is never present on the plates of young animals.

The internal surface of the plate (Plate I, Fig. 11) is smooth except the three corners which are slightly excavated as if they were places of attachment.

The type plate is 1.18 mm. across and .62 mm. long. These plates are very small and brittle, and, therefore, not many were found. The first ventral arm plate adjoins the side mouth plate and is adoral to the first lateral arm plate.

Other Ventral Arm Plates

Plate I—Figs. 27, 28

The other ventral arm plates are much broader than long, their proportions in the mature plate are about 3 to 1. However, this proportion changes in the younger plates with a decrease in breadth. The aboral margin of the plate is equilaterally sinuate with a medium deep central sinus, occupying the axial third, and rounded lobes which curve forward to form the lateral margins of the plate. The rounded lateral margins curve sharply into the adoral margin. The adoral margin is straight on either side of a large elevated central equilaterally straight-sided acute projection which occupies about the central third of the width.

The external surface (Plate I, Fig. 27) is rounded, mounting from a very thin aboral margin to the thick elevated projection on the adoral margin. The internal surface (Plate I, Fig. 28) is different, being flat in most cases, but with a slightly raised flat circular area located near the ends of the two wings of the plate. These raised areas are not so prominent on some plates as on others. The internal surface of the

projection on the adoral margin decreases so that the projection comes to nearly a sharp point.

The type plate is 1.06 mm. broad and .56 mm. from the point of projection to the innermost point on the aboral sinus. These plates are relatively small so only a few were found.

The ventral arm plates are, except the first one, similar the entire length of the arm. Their size varies with age, the younger plates being less broad compared with the older ones.

LATERAL ARM PLATES

PLATE I—Figs. 13-15

Like the dorsal arm plates, the lateral arm plates can be divided into two groups; those of the first three segments and those belonging to the remainder of the arm. The first two or three are quite distinct from those found elsewhere on the arm and will be dealt with separately.

There is a variation in the shape of the plates as they graduate in size from the oldest to the youngest. The oldest plates—omitting the first three—are short and very high while the younger ones become longer and less high with decreasing age. The young plates nearly circumscribe the vertebral ossicle being in contact on the ventral side and only separated by a small plate (dorsal arm plate) on the dorsal side. The older lateral arm plates are, however, separated by a large plate dorsally although still being in contact ventrally.

The projection of one of these plates on a plane would be a rectangle, becoming a square in the younger plates. There is a deep sinus on the ventral margin and the dorsal margin slants aborally. The plates, however, are not flat, but have a lunate shape. Nevertheless, these crescent plates are not equally curved, the ventral half is more acute than the upper half.

The outer surface (Plate I, Fig. 13) of the plate is smooth. The adoral margin is concaved with a deep notch near the

ventral margin. Through the hole formed by this notch the podia penetrate the calcarious covering of the arm. The dorsal margin is a straight edge which slopes a little adorally. The ventral margin has in its middle a semicircular sinus which is present in all the lateral arm plates. This sinus on the ventral margin is a very outstanding characteristic of some species; however, in most species the margins are in broad contact with each other. Along the aboral margin, which is convex, are the sockets for the spines. These sockets are present on nearly all the lateral arm plates (except the first three), but they are not distinct enough to satisfactorily determine the exact number of spines and tentacle plates.

The inner surface of the plates is irregular. Starting from the aboral lobe on the ventral margin there is a ridge which runs diagonally up across the plate and disappears near the upper adoral corner. The general surface slopes from this ridge to all the margins. The adoral margin is much thinner than the aboral one. This ridge, which is very pronounced, lies in a small groove which runs up the lateral side of the vertebral ossicle adorally to the canal for the podia, and aborally to the wide flaring ala.

The ventral arm plate always lies adorally to the lateral arm plate. While on the dorsal side of the arm the dorsal arm plate fits with a broad contact. The lateral arm plates are so arranged as to appear as if they overlapped each other, but this is due to their being thicker along the aboral margin than along the adoral edge.

Due to the compactness of these plates and their number in each ophiuran a great many fossil ones were found, far greater numbers than of the other plates. The type plate is 1.46 mm. high, and .90 mm. wide in the middle.

FIRST LATERAL ARM PLATE

PLATE II—Figs. 1-4

The first, second, and third lateral arm plates are all distinctively different from the rest of the lateral arm plates.

Only the first lateral arm plate will be dealt with at present. Most of this plate is enclosed within the body of the ophiuran, leaving only about one-third of it exposed on the ventral surface of the disk. The plate is composed of a shaft or the main body and a large knotted apophysis which projects at right angles from the plate. I will describe that part of the plate which is exposed on the surface of the disk first, and

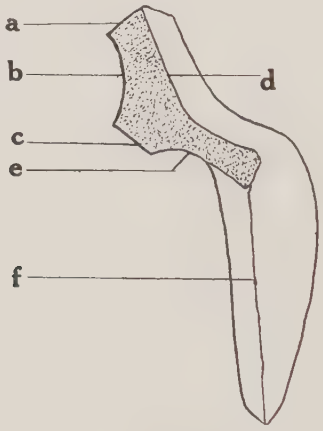

FIG. 6. Ventral view of the right First Lateral Arm Plate of *Ophiura marylandica.* a, adoral-median margin; b, median margin; c, aboral-median margin; d, adoral-lateral margin; e, semicircular sinus; f, ventral margin.

then take up the different sides of the plate in turn; the right plate being used in the description.

Part exposed (Plate II, Fig. 1, t. f. 6).

Only a small portion of the plate is exposed on the ventral side of the disk and this part is very irregular in shape. The median margin (t. f. 6, b) is mediumly concaved with sharp pointed lobes whose means; adoral-median margin (t. f. 6, a, c) and aboral-median margin; are straight, the latter being a little longer than the former. From the aboral-median margin there is a deep semicircular sinus (t. f. 6, e) which termi-

nates in a rounded point at the aboral end of the adoral-lateral margin (t. f. 6, d) which is slightly undulating. The general surface of this part of the plate is raised in the center and slopes to the margins.

The podia projects through the opening formed by the "deep semicircular sinus," which makes one side of the opening, and the other is made by the second lateral arm plate. These openings are covered in recent specimens by tentacle-scales attached along the edge of the openings. In the fossil plate the edge of this opening is perfectly smooth and curved as though there were no scales attached.

Part unexposed.

The large knotted apophysis or the exposed part is attached to the body of the plate at an angle of about 90 degrees. Viewed from the ventral side the apophysis is at about a 135-degree angle with the body of the plate. The body is a long tapering shaft, placed radially and parallel to the vertebral column, decreasing in tangential thickness aborally. Down the axis of the shaft there runs an acute ridge decreasing aborally to a stylus point at the aboral end. The two sides of the shaft form straight lines which converge in the aboral apex.

Now turning the plate over so that the side which is adjacent to the vertebral column comes into full view (Plate II, Fig. 2), the plate appears to have a trowel shape (shaft) with part of the handle (apophysis) rising from the surface of the plate. The dorsal margin is a straight line; which near the aboral end curves in toward the ventral margin, but continues in the same direction as before until it reached the apex of the plate. Here it is joined by the ventral margin (t. f. 6, f) at an angle of about 15 to 20 degrees. The ventral margin is not always a straight line, but often it is slightly undulated. The difference is due to the thinness of the plate and whether or not it has been broken. The aboral end which has been previously viewed from another angle has still a sharp apex.

The adoral margin of the body or shaft of the plate cannot be seen on account of the apophysis projecting beyond it.

The surface of the plate is irregular due to the large apophysis which rises near the adoral end of the plate. The general surface mounts gently from the ventral margin—which is thin—toward the dorsal side of the plate; but just before it reaches the dorsal margin it suddenly drops in a line parallel to the dorsal edge. This leaves a deep groove running the entire length of the dorsal margin except near the aboral apex of the plate, for here the groove is obliterated by part of the dorsal margin that has curved inward towards the opposite side. As the surface mounts towards the dorsal side of the plate it also slowly ascends towards the adoral end of the plate until it reaches the base of the apophysis, which is about one-fourth of the way from the adoral end. The surface now rises in a spiral twist of 90 degrees at an angle of 45 degrees radially to the aboral margin of the apophysis. There is a slight swelling about in the middle of the aboral base of the apophysis. Dorsad of this and a little adorally there is a projection on the edge of the groove which extends out from the base of the apophysis as far as the dorsal margin of the plate. From this projection there rises on a spiral twist of the apophysis a ridge which becomes the aboral side of the apophysis at its upper end. The ventral margin of the apophysis, from this view, appears rounded while the dorsal margin is straight with a sinus situated in the middle.

Again turning the plate over so that now the dorsal surface is uppermost (Plate II, Fig. 3) the apophysis is clearly seen forming an angle of 135 degrees radially with the main body or shaft of the plate. The groove which was seen in the previous view is now marked by a narrow ridge which runs the entire length of the body—decreasing in magnitude near the ends, near the side which is distal from the vertebral column. The two lateral margins of the plate form a straight line which converges slightly towards the aboral apex of the plate. The head of the apophysis swells out and running

down the ventral side of it, is a groove. This groove originates as the median sinus of the apophysis where it is much deeper than nearer the body of the plate.

Turning the plate over so that the side which is distal from the vertebral column is uppermost (Plate II, Fig. 4), there can be seen clearly, the apophysis at right angles transversely to the plate. The ventral and dorsal margins are the same as seen in the reverse view. The adoral margin of the plate is irregular, for the main body grades into the apophysis. One can see, however, a wide sinus running from the adoral end of the dorsal margin to the end of the apophysis—this forms the dorsal margin of the projection. The adoral end of the sinus terminates in a sharp point, the other limb of which curves back to the adoral end of the dorsal margin. The surface of the main body of the plate is similar to that on the reverse side, for the entire surface slopes gently up to near the dorsal margin when it drops down and forms a groove which parallels the edge of the plate.

The type plate is 2.30 mm. in a straight line from the aboral apex to the adoral end of the apophysis; .90 mm. wide at the base of the apophysis; 1.01 mm. from the aboral apex to place of width measurement; .56 mm. thick at this point; the median margin of the apophysis is .45 mm. and the apophysis protrudes .50 mm. from the internal surface of the main body of the plate. A great many of these plates were found though they are very brittle, all having the same shape, but varying in size.

At first glance these plates were taken for the same as the side mouth shields and it was only after careful study that the difference became clear. Also the second lateral arm plate is very similar, but the remarkable difference is that the aboral end of the plate is not pointed.

After studying some of the recent specimens I found that the two ends of the first lateral arm plate did not meet on the ventral side of the arm, and in other cases they did. Those

that did not were found to have a concaved median margin, while those that did had a straight margin. In all of the fossil specimens found the median margin was concaved, thus proving that the first lateral arm plates were not in contact with each other.

SECOND LATERAL ARM PLATE

PLATE II—Figs. 15-18

The second lateral arm plate is decidedly unlike the first lateral arm plate in not having the long stylus shaft. However, the second plate is also unlike the rest of the lateral arm plates. This plate that I am going to describe as the second lateral arm plate, might just as well be the third. The differences between the second and third are so slight that with the factor of the age of each plate found entering into the determination, it is unsafe to distinguish between them. Therefore, I have picked out the best plate—left—and have made it the type, calling it the second lateral arm plate.

Part exposed (Plate II, Fig. 15).

That part of the second lateral arm plate which is exposed on the ventral side of the arm is only a part of the entire plate. The disk and arm cover up the main body of the plate. The exposed part has an irregular shape. The median margin is mediumly concaved—as in the first lateral arm plate—with the adoral lobe forming a sharp point with the adoral-lateral margin. The aboral lobe, which is a straight line slants off towards the side that is distal from the vertebral column and forms the aboral-median margin. The adoral-lateral margin which is the longest margin on the exposed part of the plate —is slightly undulating—and its rounded aboral end joins the aboral margin of the plate. The aboral margin is a wide semicircular sinus which forms a circular opening with the next plate, through which the podium protrudes. The surface of the exposed portion is swollen, decreasing towards the margins. The general configuration of the second lateral arm

plate is very similar to that found on the first lateral arm plate, only on the exposed portion. The main body of the plate is, however, very different.

Part unexposed.

The knotted apophysis is at an angle of 90 degrees radially with the main body of the plate and from the dorsal side it appears to be an angle of 135 degrees. From the ventral view the apophysis appears as large or even larger than the main body of the plate. The lateral margin of the shaft forms a straight line. The side adjacent to the vertebral column is not as straight and it slopes towards the aboral end of the plate from the base of the apophysis. There is an acute ridge which runs down the axis of the shaft, near the side adjacent to the vertebral column, and it decreases in magnitude towards the aboral end where it joins the side of the shaft.

Turning the plate over so that the side adjacent to the vertebral column is uppermost (Plate II, Fig. 16), the somewhat trowel shape is seen; however, the trowel (shaft) is much blunter than found in the preceding lateral arm plate, and the apophysis seems to stand out more than in the other plate. The main body or shaft of the plate is nearly as wide as it is long. The dorsal margin is a straight line, but it is short for the aboral-dorsal margin begins about in the middle of the plate and slants towards the ventral margin. It is this aboral-dorsal margin that is in contact with the genital plate. The ventral margin curves strongly from the adoral margin to the aboral apex, where it meets the aboral-ventral margin. The adoral margin is hidden in this view because of the apophysis which rises from near the adoral end of the plate. The surface of the plate is irregular and rises gently towards the dorsal margin and also mounts towards the root of the large knotted apophysis.

This apophysis rises up from near the adoral end of the plate in a spiral twist of 90 degrees. Its ventral margin is rounded while its dorsal margin has a deep sinus. The aboral

lobe of this sinus is projected downward as a ridge which runs down the dorsal side of the apophysis and culminates in a projection at the base of the apophysis on the dorsal side of the plate.

Now viewing the plate from the dorsal side (Plate II, Fig. 17) a clear conception is obtained of how the apophysis projects from the main body. The side of the shaft distal from the vertebral column forms a straight line. The aboral margin of the apophysis rises at right angles from the plate while the aboral margin starts out at 90 degrees, but after a short distance it slopes adorally at about 135 degrees from the plate. This gives it the appearance of the entire apophysis slanting adorally. The ridge which was seen in the previous view running down the aboral edge of the median side of the apophysis is now very pronounced and the projection at its base is more pronounced than before.

Turning the plate so that the side which is distal from the vertebral column is brought uppermost (Plate II, Fig. 18), the outer surface of the shaft is seen. The dorsal and ventral margins are the same as when viewed from the reverse side. The adoral margin which is now seen for the first time is irregular, for it is projected into that of the apophysis. The surface of the main body or shaft is, however, anything but level, for down the center of it runs a broad ridge flanked on both sides by a valley, and near the dorsal side there is another ridge. This configuration diminishes and finally dies out at the aboral end of the plate.

The type plate is 1.68 mm. in a straight line from the aboral apex to the adoral end of the apophysis, .84 mm. wide at the base of the apophysis, .84 mm. from the aboral apex to the place of width measurement, .50 mm. thick at this point, the median margin of the apophysis is .45 mm. and the apophysis protrudes .62 mm. from the internal surface of the main body of the plate.

There were all gradations from these plates to the true lateral arm plates, but they all show the same outstanding similarities. As already stated, it is very hard to distinguish between the second and third lateral arm plates. I am positive that the first three or more lateral arm plates are distinct in themselves, for in the recent specimens worked with such was found to be the case.

SPINES

PLATE I, Fig. 26

The spines are long smooth lanceolate bodies with a blunt point. They are arranged along the aboral edge of the lateral plates. It is, however, very hard to tell just how many spines there are to a lateral plate as the number of sockets is very indistinct.

Very few spines were found fossil and these few were comparatively short in length. This fact would tend to point to a closer relationship to *Ophiura texturata* than to *Ophiura sarsii,* because the spines of the former are much shorter than those of the latter.

JAWS

PLATE II—Figs. 20-24, t. f. 7

The jaws are the most complex plate in the Ophiuran, even more so than the vertebral ossicles. Each half of the jaw itself is divided into two parts which are fused together, leaving a suture which can be readily seen. This suture runs vertically up the plate, in about the middle, and is a line of weakness. In many, or rather in most, of the fossil specimens the jaws had parted along this suture so that each half of the jaws were found in two parts, only four plates being found complete. This suture can be traced in the recent Ophiurans and its origin, I think, is unknown or has never been investigated, and I would not dare to speculate upon it for my knowledge of the growth changes in the Ophiurans is very limited. I will endeavor to describe the right half of the jaw

as viewed from each side. I have used the term inside to designate the angle formed by the jaws of adjacent arms while outside designates the angle between the right and left halves of the jaw of the same arm.

The dorsal surface (Plates II, Fig. 20, t. f. 7) of the jaw is broken up into two parts by the groove for the circumoesophageal nerve-ring. The general form, however, tapers to-

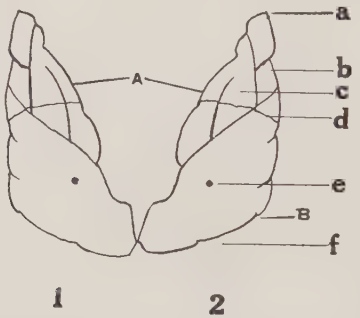

FIG. 7. Dorsal side of the right and left halves of Jaw. No. 1, left half of jaw; No. 2, right half of jaw; a, adoral end of jaw; b, groove for circumoesophageal nerve-ring; c, depression for oral tentacle; d, suture between the two parts of the jaw; e, pore for oral tentacle; f, aboral end of jaw; A, outside of jaw; B, inside of jaw. Enlarged 16x.

wards the adoral end. At the aboral end of the plate there rises vertically, from the main surface, the large ala which has a smooth adoral surface. The ala is much thicker near the outside of the plate, thinning towards the inside. At the adoral base of the ala near the outside of the plate there is a small foramen. This is the pore for the oral tentacle (t. f. 7, e) which is located about one-fourth the distance from the aboral end of the plate. This pore connects with the depression (t. f. 7, c) for the oral tentacle, which is partly seen in the dorsal view. The dorsal surface is interrupted by a diagonal line of about 45 degrees which runs from near the pore or the oral tentacle adorally towards the inside of the plate. This line forms the aboral side of the groove for the circumoesophageal nerve-ring (t. f. 7, b). The surface aborally

from this is rounded toward the lateral sides. The adoral side of the circumoesophageal nerve-ring parallels the aboral side; but is not as long, being only about one-third the length. The groove for the nerve-ring is U-shaped and not very deep. I judge this groove would be deeper in the older animals. Adorally from this groove there is a steep-sided highly-raised area which is very narrow compared with the rest of the plate, and forms the adoral end of the plate. The adoral end of this raised area is a little rounded on the inside for it is here that the left half of the jaw from the adjoining arm is in contact. Spanning this line of contact on the adoral side is located the torus angularis.

The inside edge of the plate slants slightly toward the outside of the plate, adorally from the end of the aboral side of the circumoesophageal nerve-ring. On the outside of the plate half way down there can be clearly distinguished the depression for the oral tentacle. The suture which divides each half of the jaw plate can be faintly discerned crossing the dorsal surface of the plate just aborally of the circumoesophageal nerve-ring.

Turning the plate over on its side so that the inside surface (Plate II, Fig. 21) is brought uppermost one can clearly see the suture, which divides the plate in half, running in an uneven line across the middle of the plate. The general outline of the plate is that of a rectangle which has a contracted region in the center. The inside surface of the plate is fairly simple being rounded along the lateral edges. At the aboral end, one sees in diagonal view the aboral articulating surface of the jaw. I will describe this surface viewed at right angles in a separate description later on. At the base of the ala the lateral sides which have contracted are parallel for a short distance and then flare out to the adoral end of the plate to the area of contact with the next jaw.

Just behind the ala there is a deep pit which parallels the lateral edges of the plate. This pit, which decreases in depth adorally until it disappears just aborally of the groove of the

circumoesophageal nerve-ring, is very wide occupying nearly the entire surface of the plate. Of the two rounded ridges the ventral one rises much higher from the general surface of the plate than the dorsal one. Across the adoral end of this pit the suture can be seen running in a line which forms a central sinus with two rounded lobes. Corresponding to the groove of the circumoesophageal nerve-ring there is on the ventral edge a slight indentation. From these two indentations the sides of the plate diverge outward to the nearly straight adoral end of the plate. Paralleling this adoral edge there is a narrow band of uneven surface. This rough surface is the area of contact with the adjoining jaw.

Now looking at the plate from the ventral side (Plate II, Fig. 23) again part of the aboral articulating surface is seen. The general outline of the plate is wedge-shaped, the smaller end being adorally. Just adoral of the lower alar ridge the ventral surface of the plate descends sharply, however, on the inside edge a narrow ridge which connects the ala with a large area which runs the entire length along the inside edge of the plate. This area rises adorally and culminates at the adoral end of the plate as a narrow raised dome. The rest of the ventral surface of the plate is occupied by a deep, well-rounded pit which parallels the outside edge of the plate. This pit, which is very deep at its aboral end, just adoral of the ala, decreases in depth adorally and disappears where the plate narrows. In the deepest part of the pit there is a hole which is connected with the other pores by a canal.

The general outline of the outside surface of the plate is the same as seen when viewing the inside surface. The outside surface (Plate II, Fig. 22) is very irregular being composed of a number of ridges and pits. The thick outside edge of the ala is covered with a number of minute pits and ridges. This rough surface is where the left and right halves of the jaw are in contact with each other. Running diagonally

down the center of the plate from the dorsal base of the ala towards the adoral end of the plate is a ridge which is irregular in shape. The ventral edge of this ridge is rounded, but the dorsal edge is sharp. Near the aboral end of the ridge there is a sharp, pointed projection on the dorsal side, there being a corresponding rounded swelling on the opposite side of the ridge.

On the ventral side of the ridge there is the deep pit which was so pronounced in the ventral view. Dorsad of the ridge is the deep depression for the oral tentacle which was seen in the dorsal view. The U-shaped groove for the circumoesophageal nerve-ring can be seen on the dorsal edge of the plate. The aboral side of the circumoesophageal nerve-ring seen in the dorsal view now appears to curve inward, in the outside view, and rises to the level of the aboral end of the diagonal ridge; where it unites with the thick outside edge of the ala. Just aborally of where these two meet there is a deep narrow groove which is short and runs towards the ventral side of the plate aborally.

The aboral end or the articulated surface of the plate (Plate II, Fig. 24) is different from the articulating surface of any of the vertebral ossicles. The ala is, however, divided up into a lower and upper part by a ridge similar to that found on the vertebral ossicles. The difference lies in the fact that there is a small triangular-shaped condyle with rounded crest which fits into the depression of the zygapophysis of the first vertebral ossicle. There is also near the edge of contact another rounded condyle which appears to fit into the lower part of the area between the two zygapophyses of the first vertebral ossicle. Running along the edge of contact near the dorsal part is a thin ridge which appears to have occupied the upper part of the groove between the zygapophyses of the first vertebral ossicle. This articulating surface is similarly represented on the other half of the jaw.

The type specimen of the right jaw is 2.24 mm. long, 1.46 mm. high, and .73 mm. thick at maximum measurement. The adoral edge of contact is 1.23 mm. long. The edge of contact of the ala is 1.46 mm. high.

TORUS ANGULARIS

PLATE II, Fig. 5

The torus or torus angularis, as it is called by some, is the small plate located at the intersection of the two jaw-plates. During the growth of the mouth-parts in ophiurans this plate changes. At first it is a solid plate, short and wide, but as the animal becomes older and its teeth develop; changes take place. Just as soon as a tooth is well formed, that part of the torus which is at the base of the tooth is reabsorbed and a socket is formed—which as development proceeds—perforates the plate. The plate elongates downward and the first tooth appears at the upper end of the plate. The older the plate the more perforated it becomes until its entire number of teeth are well developed.

I have found only two of these torus plates and these were taken from the ends of separate jaws which were preserved only by being fastened to a section of disk plates. These plates (torus) which are very small are rectangular, being a little more than twice as long as wide, with slightly rounded corners. The lower end is, however, broader than the upper one. The adoral surface is arched transversely of the plate and along its longitudinal axis are four distinct equally-spaced sockets which penetrate through the entire plate. The aboral surface is slightly concaved transversely, but otherwise smooth. Besides the four deep sockets the material of the plate is very spongy, more so than found in the other plates.

The most perfect of the two plates is .48 mm. long, .28 mm. wide, and .12 mm. thick. It is due to their fragility that more such plates were not found.

Since there were only four sockets and these equally spaced it would be safe to postulate that there were only four teeth, especially as these four sockets penetrated through the plate.

Teeth

Plate I, Fig. 23

The teeth arise in association with the torus plate, but are not a part of it—for the sockets in which the teeth are implanted — only form after the tooth is well developed. The first tooth appears at the upper end of the torus, later teeth appearing below. The younger the teeth are the more they are pointed.

I have found only six fossil teeth and these were taken from the same specimen that contained the two torus plates. However, all of these teeth were not in place—that is in their sockets—and thus some of them might very well be oral or tooth papillae. The fossil specimens are very minute cones—somewhat triangular—with a flat base and a rounded or blunt apex. The teeth range in length from .20 mm. to .40 mm. and in diameter at the base from .12 mm. to .20 mm. Since some of the specimens are longer than others I am inclined to think that all of the six are not teeth.

Due to their minute size very few would be found, either because they were washed away when being covered by deposits or were overlooked while picking over the samples.

Genital Plate

Plate II, Figs. 6-8

The genital plates are long thin plates of stylus-like shape. From the acute end the sides of the plate diverge slowly until near the aboral end, when they suddenly flare out and form a large swelling which articulates with the comb plate or, as some have stated, with the radial shield. The aboral end is convex.

On the ventral side of the plate (Plate II, Fig. 6) there is a straight groove which runs two-thirds the entire length from the adoral end of the plate. This groove is deeper near the adoral end. Paralleling this groove near the adoral end, on the side adjacent to the vertebral column, is another short shallow groove. It is in this latter groove that the end (shaft) of the first lateral arm plate is firmly fastened; so tightly that in recent specimens the end of the lateral plate is often broken when trying to separate the two plates. Into the other longer and deeper groove the second and third lateral plates are held only by muscle tissue. At the aboral end of the main groove there is on the side of the plate adjacent to the vertebral column a small rounded process, which extends only a short distance from the plate. This process bears evidence that it is the attachment of some muscle or tendon. The aboral end has a short groove running parallel to the axis of the plate on the side adjacent to the vertebral column. The aboral side has two condyles and one pit which are oriented transverse to the long axis of the plate.

The dorsal surface (Plate II, Fig. 7) of the genital plate is smoothly rounded until near the aboral end where the plate becomes thicker. The rounded process which extends from the side adjacent to the vertebral column is better exposed on the dorsal side. The enlarged aboral end is also better seen. This end, however, has two condyles and a deep pit running transverse, right to left, where it articulates with the comb plate.

Turning the plate over so that the side distal from the vertebral column is uppermost (Plate II, Fig. 8) the following things are found. The shaft is long and narrow, the dorsal margin being concave due to the thickening of the plate near the aboral end. The surface of the shaft is convex—to a greater degree towards the dorsal margin. The general surface rounds off at the adoral end to form a blunt point, while it rises at the aboral end into the large knotted process. This process is a little thicker a short distance from the aboral end

towards which it tapers. Across the aboral end of this knotted process there runs a wide groove. This wide groove—which is flanked on both sides by a narrow ridge—occupies the entire aboral end of the plate.

The plates are about three times as long as the width of the aboral end. The type specimen is 2.24 mm. long and 1.12 mm. broad at the aboral end. Due to the brittleness of these plates most of them were broken in half and thus very few entire specimens were found.

FIRST VERTEBRAL OSSICLE

PLATE II, Figs. 10-14

The adoral side of the first ossicle—to which the jaws are articulated—is different from that of any other vertebral ossicle. The two large zygapophyses make this difference. Similar differences are shown in the recent species of *Ophiura sarsii* and *Ophiura ophiura*. Due to the solidness of the zygapophyses of the first ossicle these plates were better preserved and I have, therefore, fully described this plate, only describing the adoral face of another ossicle. Also as the general features of the ossicles change from old to young, the first vertebral ossicle would naturally remain more or less the same.

The vertebral ossicle is surrounded by the dorsal, ventral, and the two lateral arm plates. Each arm segment contains one of these ossicles which is made up, as some have stated, of two plates grown together longitudinally. This statement that there are two plates grown together or that there is a line of weakness through their axis, caused by some other element is shown by the fact that in many of the fossil specimens only one half of a vertebral ossicle was preserved, while in others there was a deep fissure along this line of joining.

Among the many separate vertebral ossicles a great variation in shape, size, and state of preservation was found. As would be expected many of the specimens were broken or

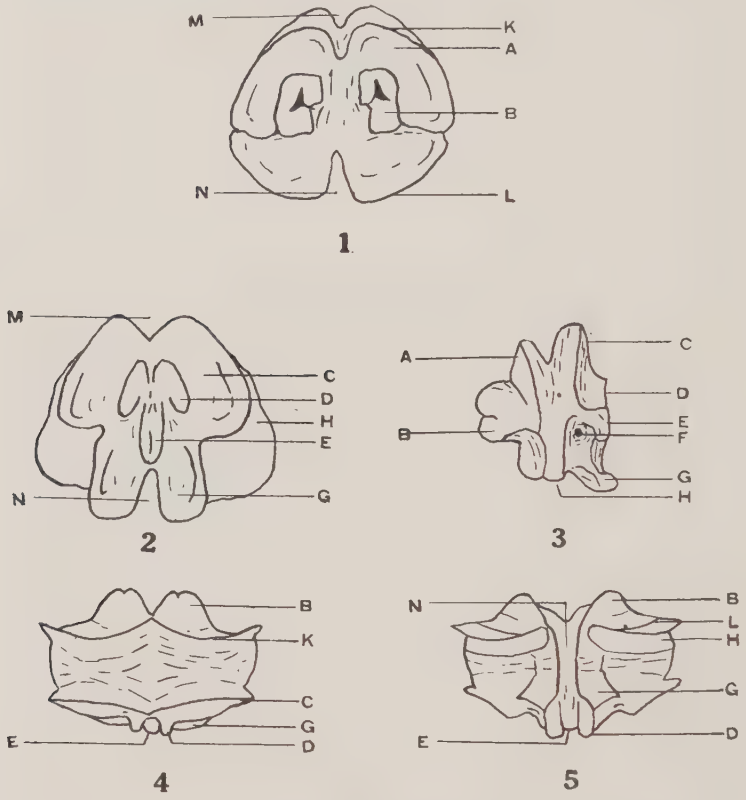

FIG. 8. First vertebral ossicle of *Ophiura marylandica*. A, ala; B, zygapophysis; C, parapophysis; D, zygocondyle; E, zygosphene; F, canal for the podia; G, anterior hypapophysis; H, posterior hypapophysis; K, upper alar ridge; L, lower alar ridge; M, upper canal furrow; N, lower canal furrow; 1, adoral side; 2, aboral side; 3, lateral side; 4, dorsal side; 5, ventral side. Enlarged 16x.

had parts broken off, like the thin alae and the zygosphene. The differences in size and shape, however, indicate differences in growth. The growth changes in the vertebral ossicles

can be traced from the young stage which is much longer than wide and wider than high, to the adult stage where the vertebral ossicle is much higher and broader than it is long. I have, however, not tried to construct a hypothetical sequence of vertebral ossicles as I did with the dorsal arm plates for there were not enough found sufficiently well preserved to make such a sequence reliable. From the size of some of the vertebral ossicles found it can safely be postulated that the arm of the fossil Ophiuran was when fully grown, made up of 60 or more segments.

Taking first the adoral end of the vertebral ossicle (Plate II, Fig. 10, t. f. 8, No. 1) the most striking things which are seen are the wide alae (t.f. 8, A) and the two centrally located condyles of the zygapophyses (t. f. 8, B). The ala which has a general circular shape is irregular along its circumference due to irregularities in growth and breaking off. It is deeply notched on both the dorsal and ventral edges. The general surface of the ala seems to be divided into two parts; the dorsal portion, which is much larger and contains the zygapophyses, and the ventral portion, whose surface is slightly inset from the dorsal portion. The upper canal furrow (t. f. 8, M) which indents the upper alar ridge (t. f. 8, K) is not so deep as the lower canal furrow (t. f. 8, N). Above the lower canal furrow there is a depression which runs vertically and connects with the upper canal furrow. It is this depression which separates the two zygapophyses.

The surface of the ala ascends abruptly near the center portion of the plate and forms the steep-sided zygapophyses; which have the same general outline—that of a rectangle whose longest dimension is vertical. The inner edge of the zygapophysis is deeply recessed about one-half the way down, just above the end of the lower canal furrow. The outer corners of the zygapophyses are slightly rounded, but still pre-

serve the rectangular symmetry. These apophyses fit loosely into pits on the aboral end of the jaws so as to insure free movement. The edges are rounded adorally and in the middle of each zygapophysis there is a deep triangular depression whose apex is directed inward. The outer lower corners of the zygapophyses are connected with the narrow ridge which separates the upper and lower half of the alae. These flat alar fields are the places of attachment for muscles. There appear to be four such muscles between each vertebra.

Viewing the plate next from the aboral side (Plate II, Fig. 11, t. f. 8, No. 2) we now have a very different surface exposed. The plate in general is still divided up into four large muscle areas and has a high articular center portion; but it is, however, very pronouncedly different from what has just been described above. The upper canal furrow (t. f. 8, M) does not indent the parapophyses (t. f. 8, C) as it did the ala. The edges of the parapophyses do not form an arc; but are slightly flattened until a little below the middle, where they suddenly curve abruptly inward toward the center of the disk—but not quite—and then flare out slightly to form the anterior hypapophysis (t. f. 8, G). This hypapophysis is entirely bisected by the lower canal furrow (t. f. 8, N). It is in this lower canal furrow that the radial vessel lies. The surface of the parapophyses and anterior hypapophyses are not level, but slope upward towards the rim and towards the narrow ridge which divides the parapophyses from the anterior hypapophyses. The ventral edge of the anterior hypapophyses extends even with the surface of the raised zygosphene (t. f. 8, E).

The zygosphene is the most prominent of the three condyles on the aboral face of the ossicle. The zygosphene, which is elongated vertically, is situated in about the center of the plate just above the lower canal furrow. On its ventral portion there is a small groove running vertically which is one of the remnants of the stage when the ossicle was not consolidated, but consisted of two plates. The two lateral

sides of the zygosphene are very steep while its dorsal end is joined by the zygocondyles (t. f. 8, D) which are much smaller and which saddle the zygosphene. All three of these condyles are like minute grains of rice in general shape. The outer sides of the zygocondyles are perpendicular and descend to the surface of the parapophyses at its deepest place. Between the two zygocondyles at the dorsal end of the zygosphene there is a slight depression which is rectangular in shape, but of very small extent. The posterior hypapophyses (t. f. 8, H) can be seen extending from behind the anterior hypapophyses.

The lateral view (Plate II, Fig. 12, t. f. 8, No. 3) of the vertebral ossicle gives a very irregular-shaped mass with the zygapophyses protruding on one side and the anterior hypapophyses (t. f. 8, G) on the other. Since this is the first vertebral ossicle, it is somewhat higher than long, but not by a large amount. The zygapophysis extends from the adoral surface as a large well-rounded dome which has a small indentation about in the middle. Rising nearly vertically from the zygapophysis is the nearly-perpendicular surface of the ala (t. f. 8, A) whose lateral edge is well seen curving down towards the ventral side of the plate. Between the ala and the parapophysis (t. f. 8, C) there is a V-shaped groove which decreases in magnitude until it disappears near the center of the lateral side of the plate. This groove is very well shown in the dorsal view. There is a very small hole in this groove just a little above the center of the lateral side. This hole is connected by a canal to the opening just adorally of the zygosphene (t. f. 8, E) in which the podium is attached. The lateral edge of the posterior hypapophysis (t. f. 8, H) is seen directly ventrally of this groove, as a narrow ridge.

The thin edge of the parapophysis curves outward ventrally near the center of the plate. Below the lower end of the parapophysis is the small openings (t. f. 8, F) of the canal for the podia. The aboral edge of the plate is made up of the flat zygocondyle (t. f. 8, D) below which can be

made out the zygosphene. Below these the side view of the anterior hypapophysis can be seen extending in a downward curve outward like a tongue.

Looking down from above towards the dorsal side (Plate II, Fig. 13, t. f. 8, No. 4) of the vertebral ossicle the upper alar ridge (t. f. 8, K) is seen as two concaved lines which meet in the center of the adoral edge. Protruding from lower down on the adoral side are the two large well-rounded zygapophyses (t. f. 8, B) each with a notch in its apex. The dorsal surface descends suddenly aborally from the upper alar ridge to a narrow V-shaped groove which is wider at the center and both ends than elsewhere. The surface now rises steeply again and culminates in the upper ridge of the parapophyses (t. f. 8, C) which is more elevated than the upper alar ridge. Like the upper alar ridge the upper parapophyses ridge is made up of two concaved lines meeting in the center of the aboral surface. Protruding from lower down on the aboral face of the plate can be seen three equally-rounded knobs which are the zygosphene (t. f. 8, E)—in the middle—and flanked by the two zygocondyles (t. f. 8, D), one on either side. The ventral edge of the anterior hypapophyses (t. f. 8, G) can be seen protruding alongside of the zygocondyles. The lateral edges of the plates are somewhat convex between the ends of the ala and parapophyses.

The outline of the ventral surface (Plate II, Fig. 14, t. f. 8, No. 5) is very similar to that of the dorsal; but the surface itself is much more complicated, for the lower canal furrow (t. f. 8, N) is very well developed. The rounded zygapophyses (t. f. 8, B) can be seen protruding from the adoral surface. The four corners of the lateral sides are formed by the lateral edges of the alae—on the adoral side—and the parapophyses on the aboral side. On the aboral side can be seen the end views of the zygosphene (t. f. 8, E) in the center with the two zygocondyles (t. f. 8, D) one on each side, which are situated about in the axial center of the plate.

Just a little aboral of the thin lower alar ridge (t. f. 8, L) —which appears to curve in from the lateral edge—are the posterior hypapophyses (t. f. 8, H). The posterior hypapophyses is a relatively wide ridge coming in from both lateral sides, but which is separated in the center by the lower canal furrow. This ridge curves slightly adorally. From its steep aboral side near the median ends the anterior hypapophyses (t. f. 8, G) rises gradually at first and then more pronouncedly and terminates just a little adorally of the aboral side so that the zygosphene and zygocondyles can be seen protruding below. Except for the two anterior hypapophyses the ventral surface of the plate slopes rapidly downward into the aboral side.

In the lower canal furrow—which is very deep—there are two openings at the inner base of each posterior hypapophysis, which can not be very readily seen. These openings are connected by canals to the two openings mentioned when describing the lateral side of the plate. The type plate is .56 mm. from the base of each canal furrow on the adoral side; .50 mm. long at greatest dimension and 1.62 mm. wide across the face of the ala at greatest dimension.

SECOND VERTEBRAL OSSICLE

PLATE II, Figs. 25, 26

As has just been stated the adoral side of the first vertebral ossicle differs from that of the other ossicles. However, the aboral sides are the same. I have taken one of the vertebral ossicles which is not the first, but which from its size and shape must be one of the earliest formed. I will describe briefly the differences which appear on the adoral side of this somewhat later ossicle.

The ala has the same shape as the first vertebral ossicle, but its surface is not broken up by two large zygapophyses as in the first vertebral ossicle. Instead the center of the disk is elevated and composed of numerous pits and ridges

to form the articulated surface. This articulated surface looks as if the two zygapophyses of the first vertebral ossicle had been placed together in the center of the disk with a little alteration. The two ridges which divide the upper ala from the lower ala, culminate towards the center into two highly elevated condyles which are separated by a deep U-shaped groove into which the zygosphene of the aboral surface fits. The inner sides of these two condyles are straight, vertical walls. These condyles protrude beyond the general surface of the rest of the articulated area, and are situated just above the lower canal furrow. From the lateral corners of these two condyles there is a narrow ridge which runs dorsally and converges until it meets just a little below the upper canal furrow. There is another ridge similar to an inverted Y which runs vertically downward from where the two outer ridges meet, the arms of which join with the two condyles. These ridges unite and form two depressions, which lie just alongside of the vertical axis of the plate, and serve as the sockets for the zygocondyles of the aboral surface of the adjacent ossicle.

HISTORY AND HABITS OF OPHIURA TEXTURATA

Ophiura texturata was formerly called *Ophioglypha ciliaris* (Linn.), *O. ciliata* (Relgius), *O. lacertosa* (Pennant), and *Ophiura texturata* (Lamarck), and *O. ophiura* (Clark). There was at the outset of this work an uncertainty as to whether to use the name *Ophiura ophiura* or *Ophiura texturata*. For it appears that one authority will use the former name for what another authority will call by the latter. H. L. Clark introduced the name *Ophiura ophiura* and has used it in preference to the other names, in his "Catalogue of Recent Ophiurans." [28] I have chosen to use *O. texturata* for several

[28] Clark, H. L., Cat. Recent Ophiurans, Mem. Mus. Comp. Zool. Harvard, Col. xxv, No. 4, p. 323, 1915.

reasons. The name *Asterias ophiura* of Linnaeus applies to a Scandinavian species which is now understood as belonging to the genus Ophiura, there are, however, in the North European seas a number of species which Linnaeus might have had in mind. To quote Th. Mortensen,[29] "it is absolutely now impossible to say which one it was. It is, therefore, perfectly unjustified now to change the name of our common *O. texturata* into *O. ophiura.*"

The distribution of *O. texturata* is very limited as compared to some of the other Ophiurans. It lives as far

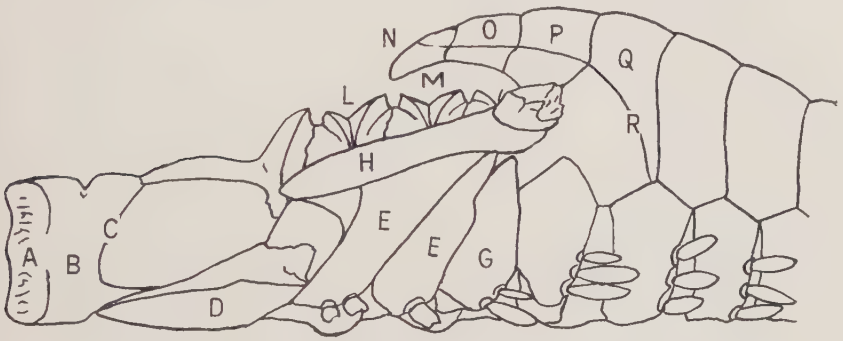

FIG. 9. View of the left side of the adoral end of the arm of *Ophiura texturata* after the disk has been removed. A, Area of contact between two adjacent jaws. B, Inside of jaw. C, Suture between adoral and aboral portions of the jaw. D, Side mouth shield. E, First lateral arm plate. F, Second lateral arm plate. G, Third lateral arm plate. H, Genital plate whose aboral condyle is broken. L, First vertebral ossicle. M, Second vertebral ossicle. N, First dorsal arm plate. O, Second dorsal arm plate. P, Third dorsal arm plate. Q, Fourth dorsal arm plate. R, Line of contact of comb plate showing papillae.

north as the Lofoten Vesteraalen region on the Norwegian coast. It is found along the entire western coast of Europe with the exception of the Baltic Sea, and along the shores of the Mediterranean and Adriatic Seas. It does not, how-

[29] Mortensen, Th., Personal letter to Prof. E. W. Berry, Aug. 7, 1932.

ever, live along the shores of Greenland and North America. Thus from its limited distribution it can be designated as an Old World species. The bathmetrical range is limited, being found in waters of shallow depths. The larva appears to be different from that of other Ophiurans, for Mortensen states [30]: "The larvae differ from all other Ophiuroid larvae known till now, in having fenestrated rods in the posterola arms," otherwise they are similar. These animals are sexually mature when they are about two years old, but it requires one or two years more before they attain their full growth.

DESCRIPTION OF PLATES OF OPHIURA TEXTURATA

Radial Shield

Plate III, Figs. 10, 11

The radial shield of *Ophiura texturata* is a modified right angle scalene triangle. It is much longer than broad, the proportions being about 2 to 1. Towards the adoral end of the plate there is a sudden incurving of the outside margin. This sinus is more pronounced in some of the plates of this species than in others. However, it is not observed on the animal when the plates are in their natural position and not separated.

The outer surface (dorsal) of the plate (Plate III, Fig. 10) is smooth and swollen near the center. The edges are bevelled, along the two longest sides, at a low angle. This shows that they were largely covered by the surrounding plates in life leaving only a small proportion exposed on the disk.

The inner surface (ventral) of the plate (Plate III, Fig. 11) is smooth with the exception of a raised area which parallels the smallest side of the plate near the aboral edge of the radial shield. This oblong condyle is a point of articulation.

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[30] Mortensen, Th., Handbook of the Echinoderma of the British Isles, p. 237, 1927.

This plate, which is the left one, is 4.99 mm. long, 2.52 mm. wide, and .39 mm. thick.

Comb Plate

Plate III, Figs. 4, 5

The comb plate of *Ophiura texturata* does not assume any special geometrical shape in outline, but is more or less irregular. The side adjacent to the arm forms a straight line which is somewhat arched. From the dorsal end of this margin the other side is formed by an arc of larger radius which becomes smaller near the ventral end where it joins the straight side at about an angle of 90 degrees. On the straight margin which is adjacent to the arm are located about 30 long, slender, stylus-like papillae, a few of which are shown in the picture still clinging to the comb plate. These papillae are an important factor in the determination of this species. Just ventral of this papillae-covered margin the edge of the plate forms a slight sinus.

The surface of the plate is smoothly arched, except near the region of the slight sinus on the side adjacent to the arm. Here the surface becomes concave along what might be called the ventral-adoral edge. The surface of the plate instead of being arched is slightly concave. This change is brought about because this part of the comb plate is overlapped by other disk plates. This area of overlapping is more pronounced in some of the comb plates than in others. The margin adjacent to the arm is thick while the other sides are thin.

The outline of the internal surface (Plate III, Fig. 5) is the same in the reverse view while the surface is very different. A little way in from the side opposite the straight side —which is adjacent to the arm—there is a ridge. At the ventral end—the center of the plate—there are two irregular condyles with a pit between them. The surface is concave

between this ridge and the side adjacent to the arm. There is a raised area running from the condyles diagonally across the plate towards the ventral corner. Ventrally of this ridge the surface slopes down towards the narrow ventral edge.

The left comb plate described above is 3.70 mm. long, and 1.68 mm. wide.

DORSAL ARM PLATES

PLATE III, Figs. 6-9

These plates which are located on the dorsal side of the arm of *Ophiura texturata* vary in shape according to their position—thus the age—on the arm. They decrease in size towards the end of the arm. Besides this variation in size the first four dorsal arm plates situated at the base of the arm are decidedly different from any of the rest. These I will describe separately.

The older plates have the general shape of a spherical equilateral trapezoid which is much wider than long. These plates are very similar to the fourth dorsal arm plate. The younger plates are shortened in width, less arched, and longer. Still younger plates are very narrow and long with their adoral margins straight and the aboral margin well-rounded.

Since the dorsal arm plates of *O. texturata* have the same general character as those from which I constructed the hypothical arm series of *Ophiura marylandica* (Plate I, Fig. 1) I have not figured any except the first four plates. I will describe these, however, in detail.

FIRST DORSAL ARM PLATE

PLATE III, Fig. 6

The first dorsal arm plate of *Ophiura texturata* is a small, semirectangular, very flat plate. The adoral margin is con-

vex, rounding into the lateral sides which flare out near the aboral margin into two rounded lobes which curve into the aboral margin. This margin is undulating. The external surface of the plate is swollen, sloping towards the lateral and adoral margins.

The internal surface is flat while the internal-aboral surface slants up to the aboral margin. On this internal-aboral surface there are two faint depressions situated in the axial center. These depressions act as sockets for the teeth of the second dorsal arm plate.

SECOND DORSAL ARM PLATE

PLATE III, Fig. 7

The second dorsal arm plate has a more definite shape than the first dorsal arm plate. It has the general shape of a modified rectangular parallelepiped, being very thick and much broader than it is long. The external surface is an equilateral trapezoid whose smaller side, which is slightly convex, is adorally placed. The aboral side is concave with two rounded lobes at each lateral end. The lateral sides of the surface are straight lines. The surface is arched transversely and is separated from the lateral sides of the plate by a groove. The surface does, however, round off to form the adoral side of the plate.

The internal surface is flat, the lateral margins of which are equilaterally rounded. The adoral margin is straight, while the aboral margin is slightly concave.

The lateral sides of the plate flare out near the internal margin. The aboral margin is concave while the adoral margin is not definite due to the fact that the lateral surface rounds off to form the adoral surface of the plate. Both the external and internal margins are straight converging slightly towards the adoral margin. The lateral sides have the general shape of rhombs.

The aboral surface is a concaved equilateral trapezoid. This surface slants up aborally from the straight internal margin to the convex external-aboral margin. The lateral margins are irregular due to the groove which separates the external side from the lateral sides.

The adoral surface is not very sharply defined, for it rounds off into the external and lateral surfaces, but it is much broader than high. There are two small teeth situated in the axial portion near the internal margin on this surface. These teeth fit into the two small depressions on the aboral side of the first dorsal arm plate. These teeth are not found in most species of Ophiurans.

This plate is .95 mm. across adorally, .90 mm. long, and .84 mm. thick adorally.

THIRD DORSAL ARM PLATE

PLATE III, Fig. 8

The third dorsal arm plate is very similar to the second with a few modifications. It is, however, larger, broader and thicker, but not much longer. The external surface is likewise an equilateral trapezoid, but its surface is not so swollen. The internal surface is now concave instead of flat as in plate 2.

The lateral sides are rhombs whose surface is flat and not flaring out towards the internal margin as in plate 2. The aboral side of the plate is a concaved equilateral trapezoid whose surface slants aborally from the internal margin to the thin convex external, aboral margin. The adoral margin is not distinctly outlined for the surface rounds off into the external and lateral margins. The surface, however, is not smooth, but rough and pitted in places.

This plate is 1.57 mm. across the adoral margin, .67 mm. long, and .78 mm. thick along the adoral margin in the center.

FOURTH DORSAL ARM PLATE

PLATE III, Fig. 9

The fourth dorsal arm plate is much broader and more arched—transversely—than any of the dorsal arm plates so far described. The external surface slopes down to form the adoral side as well as the lateral sides. The aboral surface is concave. Separating the lateral sides from the external surface are two straight grooves which converge adorally. Otherwise the lateral sides would be considered the same as the external surface, for they are in the same arc as the external surface. These lateral sides are modified rhombs.

The internal surface follows the contour of the external surface with no differentiation of the lateral sides. The aboral side slopes aborally from the rounded internal-aboral margin to the thin external-aboral margin. Like the adoral surface on the three preceding plates this surface has no definite boundaries, so I will not describe it.

This plate is 1.96 mm. across the adoral margin, .67 mm. thick on the adoral margin and 1.00 mm. long.

ORAL SHIELD

PLATE IV, Figs. 22, 23

The oral shield of *Ophiura texturata* is like an arrow-head in shape, being about one and a half times as long as it is broad. Both lateral margins of the plate are, however, not generally symmetrical; one lateral side being more pronouncedly concave than the other. The limbs of the proximal angle join at about 90 degrees in an angle whose apex is rounded. These limbs, which are straight, extend beyond the lateral sides and then curve sharply inward making a sinus with the lateral margins. The distal margin is in most specimens gently curved.

The inside surface of the plate (Plate IV, Fig. 23) is undulating and not smooth. The surface along the limbs of

the shield overlap the side mouth shields. There is an elevated region running transversely across the inner surface of the plate about one-third the distance from the adoral end of the plate. From this ridge the plate slopes downward to the distal or aboral end of the plate, which is relatively thin compared with the center of the plate. Just a little adoral of the center of the plate there is a deep rounded hole. This hole acts as a place of attachment for some ligament. However, in different plates this hole varies and is not as deep as in the one taken for the type.

The plate is 4.20 mm. in greatest length and 2.80 mm. at its maximum width.

SIDE MOUTH SHIELD

PLATE IV, Figs. 9, 10

The side mouth shield of *Ophiura texturata* assumes the shape of a trowel of which only a portion is exposed on the ventral surface of the animal. The rest of the plate is enclosed within the disk. Since part of the ventral or external surface of the plate (Plate IV, Fig. 9), is covered by the oral shield this surface is not smooth, instead it is wavy. The lateral sides form an acute point at the adoral end of the plate. The aboral margin is irregular, tending towards a point. The outside lateral-aboral margin is concave while the inside lateral-aboral margin is irregular. The outside lateral margin is undulating, while the inside margin is evenly rounded.

As I have said, the surface of the plate is wavy, for there is a rounded ridge which runs from the adoral apex to the aboral margin of the plate. This rounded ridge slopes gently down towards the outside margin where it forms a very shallow groove along the margin of the plate. On the inside of this ridge there is a wide groove, which parallels the ridge —being wider towards its aboral end. The outside edge of this groove marks the boundary where it is overlapped by the limbs of the proximal angle of the oral shield.

Now looking at the internal surface (Plate IV, Fig. 10) one sees it sloping up towards the center of the plate and towards the large apophysis situated at the aboral end of the plate. This apophysis is located in the center of the aboral end of the plate. The adoral side of this apophysis is rounded while on the aboral side there is a sharp-edged, thin ridge running down to the surface of the plate. Situated at the base of this main apophysis on its inside margin, there is a side branching apophysis. This branches at about right angles from the base of the large apophysis. Its adoral surface is rounded while its aboral side forms a rounded groove which runs down to the aboral margin of the plate. This secondary apophysis does not extend as far as the lateral margin of the plate. Both apophyses terminate in blunt ends.

The type plate is 2.52 mm. radially, 1.68 mm. at its greatest tangential width, and 1.12 mm. from the tip of the apophysis to the external surface of the plate.

I have also in Figures 5 and 6 of Plate IV shown two views of the side mouth shields of *O. texturata* united to a very thin, but high plate which lies parallel to the genital slit and forms a portion of the side distal from the arm. As can be seen in these two views this plate is rectangular in shape in side view, and very thin. This thin plate is attached to the inside edge of the groove which runs down from the secondary apophysis to the aboral margin.

First Ventral Arm Plate

Plate IV, Figs. 18, 19

The first ventral arm plate of *Ophiura texturata* is unlike the other ventral arm plates due to the fact that it is angular. The general shape of the plate is triangular, which is, however, greatly modified. The apex of the triangle is truncated to form the central one-third of the adoral margin of the plate, while the sides are slightly concave. The entire adoral margin consists of two equilateral concave sides which unite

and form a truncated projection in the center of the margin. In the center of this truncated projection there is a slight sinus. The adoral margin rounds off to form the lateral margins which in turn rounds into the aboral margin. This aboral margin is equilaterally sinuate with a medium-deep ventral sinus with rounded lobes which curve forward to form the lateral margins. The external surface of the plate (Plate IV, Fig. 18) is slightly swollen in the center sloping to the margins. It forms a shallow groove flanked by narrow lips in the center of the adoral margin.

The outline of the plate seen from the internal side is the same as in the reverse view with this exception. In the center of the sinus on the aboral margin there is a rounded lobe. The surface of the plate (Plate IV, Fig. 19) is, however, very irregular in this view. The surface slopes down to the periphery from a high rectangular-shaped area—longest axis radially—located in the center of the plate. The slope is steeper from the corners of the rectangle than from the centers of the sides. Instead of the aboral margin of the rectangle being straight, it is convex, thus forming the lobe in the sinus of the aboral margin of the plate. The surface of this rectangular area is slightly depressed. Ascending the central portion of the adoral side is a flattened area which connects with the adoral end of the rectangular area of the internal surface. This flattened area is irregularly pitted, but it has one groove which runs up its center.

This plate is 1.74 mm. across and .90 mm. long.

OTHER VENTRAL ARM PLATES

PLATE IV, Figs. 20, 21

The other ventral arm plates of *Ophiura texturata* are all similar and may be characterized by the following description of the third one of the series from the mouth. This is much broader than it is long, the proportion being about 3 to 1. The external surface (Plate IV, Fig. 20) of this

plate is swollen, rising from the thin aboral margin to the thick adoral margin. This adoral margin is straight on either side of a large elevated central equilaterally straight to concave sided acute projection which occupies about the central third of the adoral margin. The rounded lateral margin curves from the adoral margin into the aboral margin. The aboral margin is equilaterally sinuate with a medium-deep central sinus, occupying the axial third, and rounded lobes which curve forward to form the rounded lateral margins of the plate.

The internal surface of the plate (Plate IV, Fig. 21) is different from that of the reverse side. There is a raised area which runs transversely and radially across the surface of the plate forming an elevated cross. The surface rises from this thin aboral margin towards the center of the plate and towards the radially located ridge—which is pointed at both ends. The transverse ridge is slightly concave. On the adoral side of this transverse ridge the underside of the projection, so clearly seen in the reverse view, is now observed. The surface at the lateral ends of the plate rounds off to form the lateral sides.

The plate is 1.96 mm. broad, and .84 mm. from the point of the projection to the innermost point on the aboral sinus.

Lateral Arm Plates

Plate IV, Figs. 7, 8

Due to the fact that there is a difference between the first three lateral arm plates and the rest of the lateral arm plates I will describe the first lateral arm plate separately. There is a change from the old to the young lateral arm plate. The old ones are short and very high while the younger ones are long and lower. These younger plates practically circumscribe the vertebral ossicle while the older ones are separated by a wide dorsal arm plate on the dorsal side. Also in this species the first eight lateral arm plates—more or less depend-

ing on the age of the animal—are not in contact medianly with each other on the ventral side. This is one of the characteristics of this species.

The lateral arm plate of *O. texturata* which I will describe is a right one and is located somewhere in the region near the twelfth one. The shape of the plate is generally lunate, the ventral margin is rounded while the dorsal margin is straight. The adoral margin is smoothly concave while the aboral margin—which is irregular—is convex. This aboral margin is thick and the sockets of the arm spines are located along it. The center of the adoral margin forms part of the side of the foramen through which the podia are extruded. The external surface (Plate IV, Fig. 7) is swollen, rising from the thin adoral margin to the aboral margin.

Upon viewing this plate from the inside (Plate IV, Fig. 8) an uneven surface is observed. There is a slight ridge which runs from the aboral-ventral corner of the plate diagonally towards the adoral margin. In the center of the plate this ridge cumulates in a small projection. This projection is nearer the adoral margin than the aboral, and its dorsal side is rounded. The adoral margin of the plate is smoothly concave while the aboral margin—which is convex—is irregular. This irregularity of the aboral margin is due to the sockets of the arm spines which are located along this thick margin. The ventral margin is rounded while the dorsal margin is a straight side. This dorsal margin if observed from the dorsal side would form a straight margin slanting outward towards the aboral side of the plate. This slanting feature is due to the shape of the lateral sides of the dorsal arm plates.

The type plate is 2.07 mm. high and .90 mm. wide in the middle.

FIRST LATERAL ARM PLATE

PLATE IV, Figs. 1-3

As I have stated above there is a decided difference between the first three and the remainder of the lateral arm

plates; enough to warrant a separate description. I will only describe the first lateral arm plate because I was for some reason unable to secure an entire second lateral arm plate in all my dissection of this species. A great part of the first lateral arm plate is enclosed within the body of the animal leaving only a small portion exposed on the ventral surface of the disk. Roughly the plate is made up of a long shaft or main body and a large apophysis at its adoral end. For the sake of clearness I will describe the part exposed and then the part unexposed in each of the four views.

Part exposed (Plate IV, Fig. 1).

The part of the plate which is exposed on the ventral side of the disk is very irregular in shape. The median margin is concave with sharp pointed lobes. The aboral-median margin is semiconvex while the adoral-median margin is convex. There is an acute angle at the aboral end of the aboral-median margin where the semicircular sinus joins this margin. The aboral end of this sinus terminates in a sharp point with the adoral-lateral margin which curves adorally in an arc and gradually changes into the adoral-median margin. The surface of this exposed portion is swollen in the center and slopes to the margins.

There is stretched across the two lobes of the median margin a membrane-like substance which forms a small elliptical pore. This feature is only present in a few species. The semicircular sinus forms with the second lateral arm plate an opening through which the podia projects. In *O. texturata* there are from three to five tentacle scales attached along the rim of this sinus on the first lateral arm plate.

Part unexposed.

From the shaft or main body of the plate there projects from the adoral end a large knotted apophysis at an angle of about 90 degrees. Since most of the apophysis is exposed there is no reason to repeat a description of it here. The shaft of the plate is placed radially and parallels the vertebral

column. The ventral surface of this shaft is a narrow ridge which slopes steeply down and forms the lateral sides—in this view—which converge and unite at the aboral end in a point. This ridge decreases in magnitude towards the aboral end of the plate. Where the lateral and the adoral-lateral margins meet there is a slight offset and a sinus. This corner of the plate is seen in all of the views.

By turning the plate so that the side adjacent (Plate IV, Fig. 2) to the vertebral column is uppermost a totally different aspect of the plate is obtained. The plate now appears to be trowel-shaped with the apophysis acting as the handle. The dorsal margin is straight (it is broken in the one figured) and meets the ventral margin in a blunt point. The ventral margin runs parallel to the dorsal side adorally until near the adoral end of the plate where it curves suddenly outward and disappears from view under the apophysis. The true adoral margin of the plate is obscured from view by the knotted apophysis. At the aboral end of the dorsal margin there is the projection spoken of in the preceding view.

Along the dorsal margin there is a groove on the surface of the plate which parallels the said margin from the aboral end to where the adoral margin joins the dorsal side. From this groove and from the ventral margin the surface of the plate rises to a rounded ridge which runs up the center of the shaft. The surface of the plate also rises to the base of the apophysis. This apophysis rises in a spiral twist of nearly 90 degrees. The surface of the apophysis, seen in this view, slopes from the straight dorsal side down into the ventral side. The dorsal side is straight with the exception of a shallow sinus in its center. The other side is rounded. At the base of this apophysis and at the adoral end of the ridge on the shaft, there is a rounded projection which extends towards the dorsal side of the plate. From this projection there is a ridge which runs up the dorsal side of the apophysis and ends in the aboral-median margin—as seen in the ventral view.

Now turning the plate so that the dorsal side (Plate IV, Fig. 3) is uppermost. We have the same general outline as in the view from the ventral side. The apophysis projects at an angle of about 120 degrees from the shaft. The dorsal side of the apophysis is slightly concave. The projection seen at the base of the apophysis in the preceding view can be seen standing out from the lateral surface of the plate. There is a deep U-shaped groove between it and a ridge which runs down the dorsal edge of the shaft. The lateral margins of the shaft are straight, with the exception of the projection at the base of the apophysis, and they converge into a sharp point at the aboral end.

Viewing the plate from the side distal (Plate IV, Fig. 4) to the vertebral column. The plate now has the same outline as in the reverse view except the adoral margin can be observed. This adoral margin is irregular because the surface of the plate grades into the adoral side of the apophysis. The indentation at the adoral end of the dorsal margin can be observed, and from this notch the adoral margin slants towards the ventral side until it is merged in the adoral side of the apophysis. The surface of the plate is flat being bevelled along the dorsal margin and the dorsal portion of the dorsal margin.

The type plate is 3.58 mm. in a straight line from the aboral apex to the adoral end of the apophysis; 1.18 mm. wide at the base of the apophysis; 2.52 mm. from the aboral apex to place of width measurement; .62 mm. thick at this point; the median margin of the apophysis is .34 mm.; and the apophysis protrudes .90 mm. from the internal surface of the main body of the plate.

SECOND LATERAL ARM PLATE

As I have stated before, for some unknown reason I have been unable to obtain a complete second lateral arm plate from any of my dissections of this species. Every one of

the second lateral arm plates broke across at the base of the apophysis. The plate in itself is a modification of the first lateral arm plate and if the differences brought out between these two plates of *O. sarsii* are applied in this case, there will be slight danger in the determination of the second lateral arm plate belonging to *O. texturata.*

JAWS

PLATE III, Figs. 12-16

The jaws of *Ophiura texturata* are made up of two halves, the right and left, which are in turn divided into adoral and aboral parts. These two parts are fused together and the line of contact is marked by a suture, seen clearly on the outside and inside areas of the plate. I have in the case of this species illustrated both halves as they are found intact within the disk of the animal. I will, however, for the sake of brevity and simplicity only describe one-half of the jaw in each view.

Let us view the jaw first from the dorsal surface (Plate III, Fig. 12) (I will describe only the right half). The general form of the plate tapers towards the adoral end. The aboral end is wide and high for here the large ala rises vertically from the main surface. The adoral side of the ala is smooth while the aboral side is covered with sockets and condyles for articulating purposes. The aboral end of the plate is described below, separately. The ala is much thinner near its inside margin than the outside margin. At the adoral base of the ala just a short distance from the outside edge of the plate, there is a small foramen (t. f. 7, e). This is a pore for the oral tentacle and connects with the depression (t. f. 7, c) for the oral tentacle. Just aboral of this foramen there is a wide U-shaped groove which crosses the plate at about a 45-degree angle running towards the adoral edge of the plate. This groove is for the circumoesophageal nervering (t. f. 7, b) and it divides the plate into two portions. The surface aboral of this groove slopes off towards the

lateral edges. The portions adoral of the circumoesophageal nerve-ring groove is a narrow, steep-sided portion which forms the adoral end of the plate. The inside edge of this portion is flat while the outside edge is slightly rounded. This flattened side is due to the fact that the adjoining jaw is in contact along the adoral edge of the plate. The adoral end of this half of the jaw and the neighboring half are spanned by the torus angularis.

The inside of the plate appears to be vertical in this view while the outside is not, for half-way down the outside of the plate the depression for the oral tentacle can be faintly discerned. Along the ventral outside edge of the plate can be seen several mouth papillae. Also in this illustration can be seen some of the membrane which spans the two halves of the jaw and forms the adoral side of the circumoesophageal nerve-ring.

Now turning the plate over so that the inside surface (Plate III, Fig. 13) is uppermost the following configurations are observed on the left half. The plate assumes a rectangular shape; with its straight adoral end, the lateral sides converging slightly aborally, and the aboral end made up of the large ala. The surface of the plate is somewhat irregular. In the center of the plate just adoral of the inside edge of the ala there is a wide depression, occupying nearly the entire width of the plate. This depression runs towards the adoral end and decreases progressively in depth until it disappears.

This depression is bounded on both the dorsal and ventral sides by two rounded ridges which curve into the lateral margins of the plate. Just adoral of the termination of this depression on the dorsal margin there is a deep U-shaped groove, this is the circumoesophageal nerve-ring groove. In this region the inside surface of the plate slopes downward to the adoral margin. Along the inside edge of the adoral margin there is a pitted band. This band marks the area of attachment to the neighboring plate. The lateral or dorsal

and ventral sides flare out adorally in the region of the nervering groove, the dorsal one more strongly. The sides of the plate are constricted at the base of the ala and then flare out to form the adoral side of the ala. Running across the center of the plate from the dorsal to the ventral margin is an irregular line. This line is the suture where the adoral and aboral parts of the jaw are coössified.

Viewing the jaws from the ventral side (Plate III, Fig. 14) the appearance is different from that seen in the dorsal view. In this ventral view both halves of the jaw are present and they are held together by the first ventral arm plate. Many mouth papillae and tentacle scales are present, the latter being grouped about the first tentacle pore. The general shape of one-half of the jaw is very similar as seen in reverse view. There is a deep pit on the outside portion of the plate. In the dorsal end of this pit there is a hole which is connected with the other pores by a canal. At the aboral end of the plate can be seen the outline of the ala and the centrally located articulating area, in profile. Since the jaws are partly covered by the first ventral arm plate and the tentacle scales I will not describe it further. For the sake of showing the arrangement of these scales I think the lack of the full description of the jaws is justified.

Turning the plate over so that the outside surface (Plate III, Fig. 15) of the right half can be seen there appears a totally different arrangement of ridges and grooves than observed in the reverse view. The outline of the plate is, in general, similar to the reverse view except for the aboral end. Instead of the diagonal view of the ala and the articulating area, one sees a profile through the center of the articulating area, with the thick outside edge of the ala. This edge has a rough surface and marks the region of contact between the right and left halves of the jaws. There is a ridge which runs diagonally across the center of the plate from near the dorsal base of the ala towards the opposite corner. This ridge does not, however, reach this corner but dies out. The ventral

side of the ridge is round while on the dorsal side—whose edge is sharp—at the aboral end there is a sharp pointed projection. Aboral of this projection the surface of the plate drops down only to rise slowly to the outside edge of the ala. The surface of the plate drops steeply away from both the dorsal and ventral sides of this ridge, more steeply on the dorsal side, however. Just aborally of the end of this ridge there is a sharp ridge which runs down the dorsal side of the plate to the U-shaped groove of the circumoesophageal nervering. On the ventral side of this ridge there is a slight groove. Just aborally and a little ventrally of the diagonal ridge there is a deep cone-shaped pit somewhat elliptical in outline. The longest axis of this pit runs diagonally across the plate.

Placing the jaw so that the aboral end (Plate III, Fig. 16) can be distinctly seen we have the large ala surface and centrally located articulating area in the foreground while below and to both sides can be faintly discerned the main parts of the jaws. I will only describe the aboral end omitting the rest of the jaw.

There is a line or rather a minute groove which runs vertically across the surface of the plate. This groove marks the line of contact where the two halves of the jaw unite. This groove is not a straight line, but is slightly wavy. I will describe only the left half. The surface of the ala is divided into an upper and lower portion by a low ridge which runs from the lateral edge diagonally up to the base of the condyle. Along the dorsal half of the outside edge there is a narrow ridge which is higher near the dorsal end. This ridge swells out in the center of the plate and forms a condyle. This condyle, which is triangular in shape, is set off a little from the ridge towards the lateral edge of the plate. The apex of the condyle points towards the ridge. The lateral side of this condyle is perpendicular to the surface of the ala. Ventrally of this condyle the ridge swells out and is slightly wider, then it contracts only to again swell out at its ventral end

into a small, high condyle. Just dorsally of this last condyle there is a small rounded sinus in the outside edge. This appears as a small round hole when the two halves of the jaw are in contact.

The plate is 3.53 mm. long, 2.24 mm. high and 1.46 mm. thick at maximum measurement. The adoral edge of contact is 2.24 mm. long. The edge of contact of the ala is 1.29 mm. high.

GENITAL PLATE

PLATE III, Figs. 1-3

The genital plate of *Ophiura texturata* is a long stylus-like plate with a large process at its aboral end. The adoral end of the plate is bluntly rounded. This process articulates with the comb plate. Looking down on the plate from the dorsal side, this plate, which I will describe, is the left one of the pair which flanks—internally—the base of the vertebral column.

On the ventral side (Plate III, Fig. 1) of the genital plate there is a straight groove which runs up the shaft from the adoral end until near the aboral end where it disappears. This groove is deeper and more pronounced near the adoral end and is placed a little nearer the side away from the vertebral column. The first three lateral arm plates fit into this groove. There is another short narrow groove, located, partly on the process near the aboral end of the plate, which parallels the side of the plate. On the side adjacent to the vertebral column there is a swollen area which is located just adorally of the main process. From the ventral-aboral corner of the process there is a pit-like groove which runs transversely across the aboral side of the plate. This groove disappears in the center of the aboral margin and the rest of it is seen in the dorsal view. However, there is a ridge across this groove which divides it into a left and right half.

The dorsal surface (Plate III, Fig. 2) is smoothly rounded to near the aboral end where the process swells out giving an

irregular surface. The process swells out on both lateral sides, but more strongly on the side adjacent to the vertebral column. There is a small raised area in about the center of the process. Just a little adorally of this process on the margin adjacent to the vertebral column there is a slight swelling. On the aboral margin of the process there can be observed the lower or ventral edge of the pit which runs transversely across the aboral end of the plate. The adoral end of the plate is bluntly rounded.

By placing the plate so that the side adjacent to the vertebral column is uppermost (Plate III, Fig. 3) the following features can be seen. The shaft is long and narrow and on the ventral margin there can be observed a groove starting at about the middle of the plate and running to the adoral end. This groove is only a portion of that seen in the ventral view. The surface of the shaft is, otherwise, convex towards the lateral margins. The adoral margin of the plate is rounded. The aboral end of the plate is complicated for it is here that the large knotted process is located. This process rises suddenly—in side view—from the surface of the plate near the aboral end. On the ventral side of this process there is a short shallow groove which penetrates the surface from the aboral margin. There is from the aboral-dorsal corner of the process, a pit-like groove which runs transversely down the aboral end of the plate. This groove is outlined by two narrow ridges, the ventral one being the only one seen in this view.

The plate is 4.31 mm. long, and .73 mm. broad at the aboral end.

FIRST VERTEBRAL OSSICLE

PLATE IV, Figs. 11-15

Protruding from the general surface of the ala on the adoral side (Plate IV, Fig. 11) of the first vertebral ossicle of *Ophiura texturata* is the highly elevated articulating area. The ala which has a generally circular shape is notched on

both its dorsal and ventral margins. On the dorsal margin the upper canal furrow indents the upper alar ridge while on the ventral margin is located the deep lower canal furrow. Beside these two indentations in the surface of the ala there seems to be a general division of the entire alar surface into dorsal and ventral portions. This division is caused by two narrow ridges which run from the lateral-ventral corners of the zygapophyses to the circumference.

The centrally located articulating area is somewhat different from that found in the other two species dealt with in this paper. Instead of the zygapophyses being rectangular in outline they assume a triangular shape. The outside-lateral margin of the zygapophysis is convex and forms, with the ventral margin, a rounded corner. The outside-lateral margin joins the inside-lateral margin at a sharp angle, similar to that made with the ventral margin. The inside-lateral margin is not a complete unit, but is interrupted in the middle by a deep groove which broadens suddenly and forms a deep triangular depression as it runs towards the outside-lateral margin. The outside margins of the zygapophyses are perpendicular to—or in some cases overhanging—the surface of the ala. The inside margins, however, slope up from the deep groove which runs vertically across the plate from the lower canal furrow to the upper canal furrow. Also the sides of the groove which penetrate into the zygapophysis slope up to the surface of the zygapophysis. In the center of the plate in the vertical groove there is a small round condyle which does not reach the elevation of the surface of the zygapophyses. It is with these condyles and sockets that the jaws loosely articulate.

Viewing the plate from the aboral side (Plate IV, Fig. 12) the centrally located articulating region appears very different from that of the reverse side. The surface is still divided, however, into four large muscle attachment areas. The upper canal furrow does not indent the parapophysis as deeply as it does the ala. The lateral edges of the parapophysis curve

in towards the center of the disk just a little ventrally of it. Then they flare out slightly and form the anterior hypapophysis. The lower canal furrow which is very deep, bisects this anterior hypapophysis. There is a slight raised area which runs from the ventral-lateral corner of the zygocondyle to the indentation on the margin of the plate. This ridge separates the parapophysis from the anterior hypapophysis. The surface of these areas slope upward towards the rim and the dividing ridge between the two. The posterior hypapophyses can be seen extending from behind the anterior hypapophysis.

The zygosphene, which is elongated vertically, is situated in about the center of the plate just dorsal of the lower canal furrow. The lateral sides of the zygosphene rise vertically from the surface of the plate. At the dorsal end of this condyle there are located two other condyles—the zygocondyles. The zygocondyles saddle the dorsal end of the zygosphene and are slightly smaller in size even though all three bear a close resemblance to small grains of rice. Likewise the outside margins of the zygocondyles are perpendicular to the surface of the plate. Between the two zygocondyles and the dorsal end of the zygosphene there is a rectangular pit which is deeper near its ventral end.

Turning the plate over so that the lateral view (Plate IV, Fig. 13) of the vertebral ossicle can be seen the following are observed. The zygapophysis is protruding from the adoral side, and the zygocondyle and zygosphene from the aboral side. The well rounded—in side profile—zygapophysis with its apparent deep groove in the central portion extends from the surface of the ala. The surface of the ala rises nearly vertically from the base of the zygapophysis. The upper alar ridge can be seen curving down to the center of the lateral side. Likewise, the edge of the parapophysis can be seen curving down to the center of the lateral side. These two edges converge near the center of the plate and leave a V-shaped groove between them. Just ventrally of

where these two edges are in contact with each other there is a very deep pit, elliptical in shape. The lateral edge of the posterior hypapophysis can also be seen.

On the aboral side there projects the zygocondyle and the zygosphene at right angles from the parapophysis. The zygosphene is much the more prominent of the two. Near the ventral margin the parapophysis curve out slightly aborally and then back, thus forming the anterior hypapophysis, the lateral edge of which is well seen. There is a deep indentation on the ventral margin of the plate—as seen in the lateral view—which forms, on the lateral side of the plate, a deep groove. This groove terminates—a little ventrally of the center of the lateral side of the plate—in a cone-shaped pit. At the bottom of this pit there is a round foramen through which the canal for the podia passes.

In the dorsal view (Plate IV, Fig. 14) the upper alar ridge and the dorsal edge of the parapophysis appears as two bilunate lines which diverge near the lateral sides and the center of the plate. Between these two edges there is a V-shaped valley which is deeper and wider at the dorsal center of the plate. Part way down the adoral side can be seen the two zygapophyses, as well-rounded projections, each with a shallow notch in its apex. On the aboral side can be observed the zygocondyles on both sides of the zygosphene. Nearer the lateral sides can be observed the ventral edges of the anterior hypapophysis. The lateral edges of the plate appear as shallow grooves between the ala and the parapophysis.

In the ventral view (Plate IV, Fig. 15) the plate has the same general outline as in the dorsal view. The surface is, however, much more complicated. On the adoral side the two zygapophysis can be seen occupying most of the surface. They do not in this case appear as only two condyles, but instead as four. This is due to the fact that the dorsal ends of the zygapophyses appear within the space between the ven-

tral ends of the zygapophysis. On the aboral side can be observed the centrally located zygosphene flanked by the two zygocondyles.

Radially across the ventral side of the plate there is a deep groove which is the lower canal furrow which has been seen in both the adoral and aboral views. This steep-sided groove divides the surface of the plate into two parts. The surface rises from the lower canal furrow to an area—on both sides of it—which gives rise to the lower alar ridge and the ventral edge of the anterior hypapophysis. These two ridges are separated by a valley that assumes the arched surface of the plate. This valley is a little broader near its lateral end where it curves abruptly down. Here the valley terminates in a cone-shaped pit—the same as was seen in the lateral view—into which the podia fits. There are two obscure holes in the adoral end of the canal furrow which connect by a canal the pit for the podia.

The type plate is 1.18 mm. from the base of each canal furrow on the adoral side, 1.06 mm. long at greatest dimension, and 2.63 mm. wide across the face of the ala at greatest dimension.

Other Vertebral Ossicles

Plate IV, Figs. 16, 17

I have described in full the first vertebral ossicle as viewed from all sides because this ossicle is the oldest and should in all species show similar characteristics. The adoral surface of the other ossicles are different from that of the first. Otherwise they have similar characteristics on all the other sides. For this reason alone I will only describe the adoral surface of one of the other ossicles of *Ophiura texturata*—this happens to be the fourth vertebral ossicle.

The surface of the ala is the same as found in the first vertebral ossicle, but the articulating area is quite distinctive. Just ventral of the center of the plate are two triangular-shaped, highly elevated condyles whose apex point ventrally.

Between these two condyles there is a deep groove whose sides are perpendicular. This groove runs from the lower canal furrow, vertically, to the center of the plate where it dies out. It is into this groove that the zygosphene of the neighboring ossicle fits. The outside margin of the condyles is convex while the inside as well as the dorsal margin is a straight line. From the dorsal-lateral corner of these condyles there is a narrow ridge which runs to the lateral edge of the plate and divides it into an upper and lower portion. There is a narrow, straight-sided ridge which runs vertically from the center of the plate to the upper canal furrow. With this brief description of the adoral side of the fourth vertebral ossicle the differences are well brought out between it and that of the first vertebral ossicle.

DISTRIBUTION AND HABITS OF OPHIURA SARSII

Ophiura sarsii has one of the widest distributions of any of the Ophiuroidea. It is circumpolar in the Northern Hemisphere. It has been found along the Atlantic Coast of North America and Europe, and the Pacific Coast of North America, along Bering Sea, Asia, and Japan. The bathymetrical range of this species varies, for in the Pacific Ocean its range is from 5-695 fathoms [31] while elsewhere it has been recorded from as deep as 1,700 fathoms. It is, therefore, a much deeper water species than *Ophiura texturata* which apparently does not get below 200 meters. The bottom on which *Ophiura sarsii* lives varies from mud to pebbles (i.e. soft to hard) more often the former. It was found that the temperature range of the Pacific water in which it lived varied from 56.3 to 30.1 degrees Fahrenheit.[32]

The development of the larva has not been studied to any great extent, but it has been suggested that *Ophiopluteus*

[31] Clark, H. L., U. S. Nat. Mus. Bull. 75, p. 44, 1911.
[32] Clark, H. L., op. cit., p. 44.

compressus is the larva of *Ophiura sarsii.* Its growth is similar to *Ophiura texturata,* but it reaches a somewhat larger size.

DESCRIPTION OF PLATES OF OPHIURA SARSII

RADIAL SHIELD

PLATE V, Figs. 19, 22

The radial shield of *Ophiura sarsii* is a modified right angle scalene triangle whose one side—outside margin—is very undulating. The plate is about twice as long as it is wide. The outside margin which is very undulating in some specimens is modified in others. However, there is always some evidence of this irregular margin in the plates which I have examined. This irregular margin does not show on the surface of the animal because of the fact that the small surrounding disk plates overlap the edges of the radial shield.

The outer surface or dorsal side of the plate (Plate V, Fig. 19) is smooth being swollen near the center of the plate. The two longest sides of the plate are beveled at a low angle showing evidence of being overlapped by the neighboring disk plates. The part which is thus left exposed is only about two-thirds the total area of the plate. The plate is slightly curved radially.

The inner or ventral surface of the plate (Plate V, Fig. 22) is smooth with a swollen area across the aboral end of the plate. This swollen area is composed of two slightly raised portions separated by a shallow sinus. The condyle towards the outer margin of the plate is evidently rounded, while the other—towards the inside margin—has a wide shallow groove running down its aboral side in a sweeping curve towards the dorsal side in an outside marginal direction. This groove dies out, however, when it reaches the aboral margin of the plate, but its presence is marked by a slight indentation on the aboral margin of the plate. Just adoral of these two

condyles there is a small rounded area which marks the muscle attachment.

The radial shield of *O. sarsii,* which is the right one is 5.76 mm. long, 3.77 mm. wide and .56 mm. thick in the middle.

COMB PLATE

PLATE V, Figs. 4, 5

The comb plate of *Ophiura sarsii* has the general shape of a trapezium which is twisted at an angle of about 90 degrees along its longest axis and with its shortest axis strongly arched. The longest side is adjacent to the base of the arm. The external surface of the plate is smoothly curved, but there is a depression of the surface near the ventral margin which marks where the plate was overlapped. Along the longest side, which is adjacent to the base of the arm, there are 15 small stockey comb papillae. These papillae range in size, the largest one being on the dorsal end while the smallest is near the ventral end. These comb papillae are important factors in the determination of the different species when the comb plate is present. The ventral margin of the plate—which has a shallow sinus in its middle—is very thin due to the fact that it is covered by neighboring disk plates.

The internal surface (Plate V, Fig. 5) of the plate is similarly twisted to the external surface being convex except in the ventral region. There is a line running from the lower inside corner diagonally to about the middle of the opposite side. To the outside of this line the internal surface of the plate is concave. There is a slight raised area near the dorsal end of this line. This raised area and the swollen area just opposite on the outside margin—seen in internal view—acts as the articulating surface of the plate.

The plate is 3.60 mm. long and 1.77 mm. wide in maximum dimension.

Dorsal Arm Plates

Plate V, Figs. 6-9, 16

The plates which are located on the dorsal side of the arms show a great variation due to the gradation from old to young plates. I have discussed at some length these changes in gradation of the dorsal arm plate in dealing with *Ophiura marylandica.* I have also constructed a hypothetical series of dorsal arm plates of this species. In general characters the dorsal arm plates of *O. sarsii* are the same as *O. marylandica* with the exception that there appear to be no teeth on the adoral margin or sockets on the ventral-aboral margin of *O.Sarsii.* There is another variation which does not always appear in *O. sarsii.* This is that sometimes there appear to be 5 instead of the usual 4 dorsal arm plates at the base of the arm which are distinct from the rest of the dorsal arm plates. Why this variation is present I am uncertain, but in counting these plates in a number of specimens I have found this to be true. Due to this variation I have taken a case where there are five distinct dorsal arm plates to describe.

first dorsal arm plate

Plate V, Fig. 6

The first dorsal plate has a modified turbinate or wedge form, the apex of which is placed adorally while the aboral margin is concave. The lateral sides of the plate curve in aborally and then run in a straight line aborally toward the aboral margin. These straight lateral sides form sharp angles with the lateral ends of the aboral margin. The adoral surface of the plate slants toward the external surface aborally. Very little of the dorsal surface of the plate is exposed and that little is well rounded. The aboral side is slightly concave transversely and prallels the adoral side. The internal or ventral surface is flat and is cordate in shape, the apex being adoral.

SECOND DORSAL ARM PLATE

PLATE V, Fig. 7

The general shape of the dorsal arm plate is that of a modified rectangular parallelepiped whose greatest dimension is in breath. That part of the plate exposed on the dorsal side is very little, but it takes the general shape of an equilateral trapezoid with the smaller parallel side adoral. The surface rounds from the adoral and lateral sides and forms a dome-like external surface, the aboral margin of which is slightly concave.

The adoral surface has no sharp limits except along the internal margin where it forms a sharp angle with the internal surface. Otherwise the adoral surface rounds into the lateral and external surfaces.

The internal surface has the shape of an equilateral trapezoid whose longest parallel side is concave. This is very narrow and very broad. The aboral surface is a concave equilateral trapezoid with the lateral sides flaring out strongly near the internal surface. There are no distinct lateral sides for the adoral and dorsal surfaces round into a very narrow lateral side too indistinct to describe.

The plate is .84 mm. across adorally, .45 mm. long, and .56 mm. thick adorally.

THIRD DORSAL ARM PLATE

PLATE V, Fig. 8

The third dorsal arm plate is the same in character as the preceding one except that it is larger, being broader, thicker, and a little longer than the preceding. Otherwise it is the same and I think it is, therefore, unnecessary to describe it in any more detail. The plate is 1.18 mm. across the adoral margin, .34 mm. long, and .67 mm. thick along the adoral margin in the center.

FOURTH DORSAL ARM PLATE

PLATE V, Fig. 9

This plate, although it bears a close resemblance to the two preceding plates, is very distinctive. The external surface has the outline of a modified equilateral trapezoid whose surface is arched transversely. The adoral margin curves down to form the adoral side of the plate. The aboral margin is slightly concave. The lateral sides of the plate are separated from the external surface by a narrow ridge and from the adoral side by a slight groove. The surface of the sides is slightly raised from that of the rest of the plate. These lateral sides are not vertical in position, but follow the general curve of the plate.

The internal surface is smoothly concaved and slopes aborally towards the external side. There is really no distinct adoral or aboral side for in the former the external surface rounds down into the adoral surface, while in the latter the internal surface slopes up and forms a sharp edge with the aboral margin of the external surface.

The type plate is 1.57 mm. across adoral margin, .90 mm. thick on the adoral margin, and 1.45 mm. long.

FIFTH DORSAL ARM PLATE

PLATE V, Fig. 16

The fifth dorsal arm plate has a very wide arch and is very thin. The only reason for including it in the group with the above dorsal arm plates is the fact that on each limb of the plate on the dorsal surface are the remnants of the lateral sides. This vestige of the lateral side is marked off by a narrow groove running diagonally across the limbs of the plate from the adoral side to the corners of the aboral side. The plate is thicker along the adoral side thinning towards the aboral margin. The internal surface of the plate parallels the external surface thus being widely arched. The indentation on the adoral margin in the figure of the plate is due to a broken place in the plate.

The plate is 3.36 mm. from one limb to the other, .45 mm. from adoral to aboral margin.

INTERRADIAL MARGINAL PLATE

PLATE VI Figs. 9, 10

The interradial marginal plate of *Ophiura sarsii* is elliptical in outline. The external surface of the plate (Plate VI, Fig. 9) is smooth, being arched along the shorter axis. The surface rounds off slightly at the end of the longer axis. The internal surface (Plate VI, Fig. 10) rises gradually from the two ends of the plate, towards the center, where it culminates in a broad flattened ridge which parallels the shorter axis. There do not appear to be any marked places of attachment which I have been able to observe on the internal surface of the plate.

The plate is 2.46 mm. along the longer axis, 1.68 mm. along the shorter axis, and .50 mm. thick at the center.

ORAL SHIELD

PLATE VI, Figs. 22, 23

The oral shield of *Ophiura sarsii* has a flattened arrowhead shape being one and a quarter times as long as it is broad. The sides of the broad proximal angle unite in a point making about a 100 degree angle with each other. The limbs are straight or even convex in some specimens and extend beyond the lateral margins of the plate. The ends of the limbs curve in making a rounded sinus in some specimens, but most usually form an angle with the lateral margin of the plate. The lateral margins converge slightly towards the distal side. The distal margin is evenly rounded. The outer or ventral surface (Plate VI, Fig. 22) of the plate is smoothly rounded being a little higher near the center of the plate.

The inside or dorsal surface of the plate (Plate VI, Fig. 23) is very irregular. The surface along the limbs of the proximal angle is depressed, leaving a pronounced ridge run-

ning from the apex of the proximal angle to the center of the plate where it unites with two ridges which come in from the lateral margins. These depressed areas along the proximal angle show where this plate overlaps the side mouth shields. The raised areas which come in from the lateral margins cross the plate, transversely about in the center of it. Where these three ridges meet there is a slight depression which is situated in about the center of the plate. From these transverse ridges the surface of the plate slopes gradually downward towards the distal margin. There is no marked difference on the inside surface of the plate in this region to show where it has overlapped other disk plates.

The plate is 3.14 mm. in greatest length and 2.69 mm. at its maximum width.

Side Mouth Shield

Plate VI, Figs. 5, 6

The side mouth shield of *Ophiura sarsii* is a very narrow trowel-shaped plate with, however, only a small portion exposed on the ventral side of the animal. I will endeavor to describe the right one. Since part of this plate is covered by the oral plate the entire plate is very different in appearance. The plate as stated above is trowel-shaped, the apex being placed adorally. The aboral end of the plate is irregular due to the apophysis which rises from the interior surface. On the outside margin there is a deep rounded sinus near the aboral margin. The surface is swollen, but near the inside margin there is a furrow which runs from the aboral margin nearly to the adoral apex. The furrow is wider tangentially near the aboral end. This furrow is caused by the overlapping of the oral plate. The outside rim of the furrow marks the line of the outside edge of contact. Part of the apophysis can be seen descending from the internal surface at the aboral end of the plate.

The outline of the side mouth shield as seen from the interior (Plate VI, Fig. 6) is the same as in the reverse view

with the exception that now the apophysis at the aboral end of the plate gives this margin an acute apex. The general surface mounts up from the periphery towards the aboral end of the plate where it culminates in a high narrow apophysis. This apophysis is placed in the center of the aboral end and terminates in a sharp point. The apophysis is a little longer than it is thick. Its end is attached to the adoral end of the genital plate as can be seen in t. f. 9.

The type plate is 2.91 mm. radially, 1.46 mm. at its greatest tangential width, and 1.12 mm. from the tip of the apophysis to the external surface of the plate.

FIRST VENTRAL ARM PLATE

PLATE V, Figs. 10, 18

The external surface of the first ventral arm plate (Plate V, Fig. 18) is smooth and well rounded, curving downward more towards the adoral margin than towards the aboral margin. The rounded lateral margin curves aborally into the sharply converging sides of the aboral margin. There is a slight offset about one-fourth the way in from the lateral margin. From this offset the margin is straight or slightly sinuate and culminates in a rounded point in the center of the aboral margin. The aboral margin is just as irregular with a rounded sinus near the lateral margin, then a rounded lobe followed by a very slight sinus and then a broad well-rounded lobe which occupies the center one-third of the adoral margin of the plate.

The internal surface (Plate V, Fig. 10) is very uneven. The surface mounts gradually from all sides towards the central portion of the adoral margin where it culminates in a pronounced elevated condyle. The surface slopes more gently from the four corners of the plate than it does from the center of the aboral margin and the two lateral margins. The apex of the above-mentioned condyle is located about one-third the distance in from the adoral margin of the plate.

The plate is 1.75 mm. broad and 1.13 mm. long in greatest dimension.

Ventral Arm Plates

Plate VI, Figs. 19, 20

The ventral arm plate of *Ophiura sarsii* change in its size proportionately with the age of the plate. In the mature plate it is about three times as broad as it is long. The aboral margin of the plate is straight, the ends of which curve forward to form the lateral margins of the plate. The adoral margin of the plate joins the lateral margin in a sharp angle. The adoral margin is straight on either side of an acute projection equilaterally straight sided which is situated in the middle of the adoral margin. This projection is elevated from the surface of the plate. The surface, however, gradually slopes from the aboral margin up to this adoral projection.

The internal surface (Plate VI, Fig. 19) is flat except for two slight depressed areas situated near the center of the plate. The internal surface of the projection on the adoral margin, which can be seen in this view, is prominent showing, however, a smooth surface.

Although these plates vary greatly in size according to their age this plate is 2.35 mm. broad and .73 mm. from the point of the projection to the aboral margin.

Lateral Arm Plates

Plate VI, Figs. 7, 8

Since there is such a great distinction between the first three lateral arm plates and the rest of the lateral arm plates I will describe the first and second separately. Besides the difference found in the first three plates there is some variation in the younger plates. The older plates are short and very high while the younger ones are longer and less high. This change grades through the old to the young plates. The young plates practically circumscribe the vertebral ossicle

while the old ones are separated on the dorsal side of the arm by the dorsal arm plate, remaining, however, in contact with each other on the ventral side.

I will describe one of the lateral arm plates—the right one —as viewed from the dorsal side. The shape of the plate is in general lunate the dorsal end being pointed while the ventral end is round. The outer surface (Plate VI, Fig. 7) of the plate is smooth, sloping out towards the aboral margin. The aboral margin—which is thick—is uneven, due to the sockets of the spines which are located on this side. The adoral margin is thin and in its center there is a shallow sinus. This sinus forms the aboral side of a pore through which the pidia penetrates.

Viewing this plate from the inside (Plate VI, Fig. 8), the uneven surface can be clearly seen. There is a ridge which runs diagonally from the aboral-ventral corner of the plate towards the adoral margin. The dorsal end of this ridge terminates in a small projection which can be observed on the adoral margin in both the interior and exterior views. The shallow sinus seen on the adoral margin in the reverse view can be distinguished. Otherwise the margin is regular. On the aboral margin, which is irregular, is a large projection near the ventral end of the plate. The surface of the plate slopes from the diagonal ridge towards the periphery. This ridge fits into the groove on the lateral side of the vertebral ossicle. The dorsal margin appears to be pointed while the ventral margin is round.

The type plate is 2.63 mm. high and .67 mm. wide in the middle.

FIRST LATERAL ARM PLATE

PLATE VI, Figs. 1-4

I have taken the left one of the pair of first lateral arm plates to describe. As I have previously stated, the first three lateral arm plates are distinctly modified from the rest of the lateral arm plates. Most of this plate is enclosed within

the body of the Ophiuran. The plate is made up of a long shaft or main body and a large knotted apophysis which is at right angles with the shaft. It is best, I think, to describe the part exposed first and then the part covered, in dealing with each view.

Part exposed (Plate VI, Fig. 1).

Viewing the plate first from the ventral side only a small portion of it is exposed. The median margin (t. f. 6, b) is straight and is joined by the adoral-median margin in a sharp angle (t. f. 6, a). There is no aboral-median margin present. The adoral-median margin is slightly convex and curves around the adoral end of the plate into the adoral-lateral margin. The median margin is joined on its aboral end—making a sharp angle—by a deep semicircular sinus (t. f. 6, e) which terminates in a rounded point at the aboral end of the adoral-lateral margin. The adoral-lateral margin (t. f. 6, d) is irregular in shape being slightly sigmoid in outline. The general surface of this exposed part of the plate is convex. It is through these semicircular sinuses that the podia project, and they are covered by tentacle scales.

Part unexposed.

The large apophysis is attached to the shaft or main body of the plate at an angle of about 90 degrees which, when viewed from the ventral side, appears to make an angle of about 130 degrees. This main body is a long tapering shaft which decreases in thickness aborally, ending in a sharp stylus point, when the end has not been broken off as is the case in the plate figured. Down the center of the shaft there is a ridge running the entire length.

Turning the plate over so the side adjacent to the vertebral column is clearly seen (Plate VI, Fig. 2) the plate takes the shape of a trowel with the apophysis acting as the handle. The dorsal margin of the plate is straight, curving slightly towards the ventral side near the aboral end of the plate,

making a sharp point at the aboral end. The ventral margin is, however, not a straight line, but undulating. This undulation is due to the thinness of the plate and chance breakage. The aboral end of the ventral margin incurves slightly to form the aboral apex. The large apophysis hides the adoral margin of the plate from view.

The surface of the plate is irregular with the large apophysis rising near the adoral end and the groove which runs down the length of the shaft. The surface, which rises gradually from the thin ventral margin towards the dorsal margin, drops suddenly in a line paralleling the dorsal edge. This makes a deep groove along the entire dorsal edge of the plate from the aboral apex of the plate to the adoral end. The surface of the plate likewise ascends to the base of the apophysis at the adoral end of the plate where it suddenly ascends in a spiral twist of 90 degrees at an angle of about 45 degrees radially to the aboral margin of the apophysis. At the base of this apophysis on the dorsal side near the adoral end of the groove—which parallels the dorsal side—is a pronounced projection. This projection is quite large with a rounded apex. Both the dorsal and ventral margins of the apophysis are convex.

Now viewing the plate from the dorsal side (Plate VI, Fig. 3) the apophysis is seen forming an angle of 135 degrees with the main body of the plate. The lateral margins of the plate form straight lines, converging towards the aboral end where they meet in a point.

There is a slight depression on the surface of the head of the apophysis. The projection seen at the base of the apophysis in the interior view is pronounced in the dorsal view. This projection is much longer radially than it is thick and there is a deep groove just to the outside of the projection.

Now viewing the plate from the side which is distal (Plate VI, Fig. 4) from the vertebral column the following features can be discerned. The ventral and dorsal margins are the

same as seen in the interior view. The adoral margin of the plate is irregular for the apophysis forms part of it. The surface of the shaft is irregular for there is a groove running the entire length parallel to the dorsal margin. The rest of the surface of the shaft is smooth. The surface at the adoral end of the plate slopes down and forms the adoral side of the apophysis.

The type plate is 3.86 mm. in a straight line from the aboral apex to the adoral end of the apophysis; 1.12 mm. wide at the base of the apophysis; 2.35 mm. from the aboral apex to place of width measurement; .84 mm. thick at this point; the median margin of the apophysis is 1.00 mm.; and the apophysis protrudes 1.57 mm. from the internal surface of the main body of the plate.

SECOND LATERAL ARM PLATE

PLATE V, Figs. 15, 17, 20, 21

The second lateral arm plate of *Ophiura sarsii* differs mainly from the first lateral arm plate in not having the long shaft. Otherwise it is very similar. I will describe the diagnostic characters of the left one, first the part exposed and then the part unexposed.

Part exposed.

The part exposed on the ventral side of the arm (Plate V, Fig. 15) is irregular in shape and comprises but a small portion of the plate. The rest is covered up by the main body of the plate. The median margin is slightly convex, rounding off into the adoral- and aboral-median margins. The adoral-median margin rounds off into the adoral-lateral margin. The aboral-median margin unites with the adoral margin in a sharp angle. The aboral margin is a wide semicircular sinus which forms with the next plate a circular opening for the podium to protrude. The aboral ends of the aboral margin and the adoral-lateral margin meet in a rounded, acute angle.

The surface is swollen in the middle of the exposed part, decreasing towards the periphoral.

Part unexposed.

It is the unexposed part that differs widely from that found in the first lateral arm plate. The apophysis appears to be at an angle of 135 degrees with the main body of the plate, but is really at an angle of 90 degrees radially. The lateral margins of the shaft are straight, converging in a point at the aboral end of the plate. The margin of the side adjacent to the vertebral column is not as straight as the distal margin, there being a slight offset near the aboral base of the knotted apophysis. There is an acute ridge which decreases in magnitude towards the aboral end running down the axis of the shaft.

Viewing the plate from the side adjacent (Plate V, Fig. 20) to the vertebral column the trowel shape can be clearly discerned with its handle—knotted apophysis—standing up from the shortened shaft. The shaft of the plate is as wide as it is long. Both the dorsal and ventral margins of the plate are uneven, being serrated. They do, however, unite in an apex at the aboral end of the plate. The dorsal and ventral margins curve in at their adoral end and form the adoral margin of the plate which is hidden from sight in this view because of the apophysis. The surface of the shaft rises from the aboral apex and the lateral sides to the base of the high apophysis.

The apophysis, which is situated at the adoral end of the plate, rises up in a spiral twist of nearly 90 degrees. The general outline of the surface of the apophysis thus seen, is elliptical with, however, the adoral end of the ellipse pointed instead of round. The surface of the apophysis is greatly swollen with a decided rounding off along the aboral-dorsal side. There is a slight narrow ridge running down the dorsal side of the apophysis from this adoral-dorsal point to the

dorsal side of the shaft. This ridge is hard to discern in most cases because the head of the apophysis hides it from view.

Now turning the plate over so that the dorsal side (Plate V, Fig. 17) is uppermost the apophysis can be seen projecting from the shaft of the main body, being a great deal larger than the shaft. The adoral margin of the plate joins the side distal from the vertebral column of the shaft at right angles. Then the adoral side suddenly flares out and forms the margin of the large round—in dorsal view—apophysis. The sides of the shaft distal and adjacent to the vertebral column converge into a rounded apex at their aboral end. The surface of the apophysis is slightly concave while the surface of the shaft is irregular, there being a groove running the length in the middle of the shaft. This groove is very deep near the aboral end, thus forming a high ridge on the side adjacent to the vertebral column. This groove dies out towards the adoral end of the plate.

Viewing the plate from the distal or exterior side (Plate V, Fig. 21) the outline of the shaft is the same as seen from the interior side. However, the adoral margin of the plate, which is seen for the first time, is irregular in outline due to the apophysis. The surface of the plate is swollen diminishing towards the periphery. Near the dorsal margin of the shaft is a straight groove which runs to the adoral margin. The surface of the shaft rounds suddenly down to form the adoral side of the apophysis.

The type plate is 2.24 mm. in a straight line from the aboral apex to the adoral end of the apophysis; 1.23 mm. wide at the base of the apophysis 1.00 mm. from the aboral apex to the place of width measurement; .56 mm. thick at this point; the median margin of the apophysis is .57 mm. and the apophysis protrudes 1.12 mm. from the internal surface of the main body of the plate.

SPINES

PLATE VI, Fig. 16

The spines of *Ophiura sarsii* are very long and tapering. They are not completely round being somewhat flattened on two sides so that a cross section would be elliptical. These long lanceolate spines are one of the characteristic features of this species.

JAWS

PLATE V, Figs. 11-14

Viewing the left half of the jaw of *Ophiura sarsii* from the dorsal side (Plate V, Fig. 11) one can see the circumoesophageal nerve-ring dividing the surface—which tapers towards the adoral end—into two parts. Rising from the surface at the adoral end of the plate is the large ala, whose adoral surface slopes smoothly up from the main surface of the plate. At the adoral base of the ala there is a round hole —in the middle—which is the pore for the oral tentacle and connects with the depression for the oral tentacle. The ala is much thicker near the outside of the plate than elsewhere. The surface at the adoral base of the ala is smooth with the exception of the foramen, and rounds off towards the lateral margins of the plate. This surface is interrupted by a sharp drop in elevation which forms a diagonal line running from near the foramen adorally towards the inside of the plate. The side thus formed acts as the adoral margin of the U-shaped circumoesophageal nerve-ring, the other side of which is only about one-third as long, but parallels it.

There rises adorally from this groove a high steep-sided, very narrow area which terminates in the adoral end of the plate. The surface of this narrow raised area is slightly arched. The depression for the oral tentacle can be distinctly seen on the outside of the plate. This depression occupies nearly the entire outside surface of the plate.

Upon turning the plate over so that the inside surface (Plate V, Fig. 12) can be seen there are several features

which are strongly emphasized. There is the general rectangular shape of the plate with a contracted region in the center, the suture which runs diagonally across the plate and the diagonal view of the aboral articulating surface of the jaw. The description of the last will be found on the following pages. The above-mentioned suture crosses the plate in a diagonal direction as an uneven line.

From just adorally of the ala, where the lateral sides of the plate are contracted, the sides diverge gradually until in the region of the groove of the circumoesophageal nerve-ring; then the sides flare out suddenly to the adoral end where the plate is attached to the neighboring jaw. There is in the center of the plate just behind the ala a deep depression occupying most of the plate which parallels the lateral sides of the plate. This plate decreases in depth adorally until it disappears entirely in the region where the circumoesophageal nerve-ring groove is located. The two bordering ridges of this pit are of different heights, that on the ventral side being developed to a much greater degree than the other. On the ventral side of the plate there is a slight groove which corresponds in position to the circumoesophageal nerve-ring groove on the dorsal edge. Along the dorsal end of the plate there is a band of deeply-pitted surface. This is the area where this jaw is attached to the jaw of the adjoining arm.

Viewed from the ventral side (Plate V, Fig. 13) the outline and surface of the plate appear very similar to that seen in the dorsal view. There is, however, quite a difference in the surface of the ventral side. The aboral margin of the plate is very irregular due to the fact that it shows the aboral articulating surface of the jaw in cross-section. Just adoral of the lower alar ridge the surface descends sharply into a deep pit. This pit is circumscribed at its aboral end by the lower alar ridge and two ridges, one which runs along the inside margin of the plate and the other dies out on the outside margin of the plate. The ridge on the inside margin

becomes broader and more elevated until it makes up the entire width of the plate at the adoral end. There is near the adoral end a sudden break in the gradual rise of this ridge. Here there is a very steep ascent and there it flattens out. The edges of this ridge are rounded. The pit in the center of the plate decreases in depth adorally. In the aboral end of the pit there is a foramen which connects with the hole seen in the dorsal view.

The outline of the plate in the outside view (Plate V, Fig. 14) is practically the same as seen in the inside view. The surface of the plate is, however, very irregular. There is a high narrow ridge which parallels the ventral margin of the plate from about one-third the distance from the aboral margin to where it unites with the surface of the plate near the adoral margin. The surface of this ridge is well rounded while on the dorsal edge at the aboral end is a sharp projection. There is a deep depression running across the plate between the aboral end of this ridge and the thick roughened surface of the outside margin of the ala. This depression has, however, one deep round depression in it near the adoral edge of the outside margin of the ala and a small round hole running through the aboral end of the ridge; the other end of this hole is seen on the ventral view. The roughened surface of the outside margin of the ala is where the left half unites with the right half of the jaw.

On the ventral side of the ridge the surface of the plate drops off suddenly and forms part of the surface of the plate on the ventral side. On the dorsal side of this ridge there is a deep rounded pit in which the oral tentacle is situated. This pit is partly bounded on the dorsal side by a small ridge which rises near the circumoesophageal nerve-ring groove and runs aborally to the roughened margin of the ala. Part of the U-shaped groove for the circumoesophageal nerve-ring can be seen. From this nerve-ring groove the dorsal margin flares out suddenly towards the adoral margin of the plate. There is, however, a slight indentation situated in the middle

of this portion of the dorsal margin. There is on the ventral margin of the plate a groove opposite that of the nerve-ring. This groove is, however, very slight. The adoral surface of the plate is smooth and rounds off to a straight adoral margin. Across the center of the plate the suture can be seen running in an arc adorally—that is, in the center of the deep rounded pit.

Now viewing the plate so that the aboral or articulating surface (Plate VI, Fig. 21) is uppermost. One sees a different arrangement of condyles and sockets than in any of the vertebral ossicles. This is divided into an upper—which is, of course, very large—and a lower part. This division is caused by the fact that the lower part is set back from the surface of the upper part. There is a small rounded condyle about two-thirds the distance from the dorsal edge of the upper ala near the outside edge. Just above and below it nearer the outside edge are two not very strongly marked sockets. The entire edge (outside edge) of the upper ala is raised above the general surface of the ala.

The type specimen of the left jaw is 2.97 mm. long, 2.58 mm. high, and 1.23 mm. thick at maximum measurement. The adoral edge of contact is 2.58 mm. long. The edge of contact of the ala is 1.68 mm. high.

Genital Plate

Plate V, Figs. 1-3

The genital plate of *Ophiura sarsii* is a long stylus-like plate which has a swollen articulating process at the aboral end while the adoral end is bluntly pointed. Viewing the ventral side (Plate V, Fig. 1) first one sees a groove which runs up the apparent middle of the plate from the adoral end until within a very short distance from the aboral end. This groove is deeper near the adoral end becoming shallower near the enlarged head; and is replaced by a deeper groove, commencing where the head starts to swell and runs nearly

to the aboral end. On the side of the groove on the shaft adjacent to the vertebral column the ventral surface of the plate forms a low ridge while on the other side of the groove there is a very high ridge which occupies most of the shaft. It is in this groove that the first three lateral arm plates are held. This ridge is well seen in profile in the lateral view. The adoral end of the shaft is irregularly rounded off into a point.

The aboral end of the plate is irregular with the end of this high ridge forming most of the ventral surface. There are clearly two pits separated by a small condyle on the aboral margin of the process which clearly indicate that the plate is articulated to some other plate. These pits are oriented transversely to the long axis of the plate.

Now viewing the dorsal side of the plate (Plate V, Fig. 2) the configuration is much simpler. The surface of the shaft is smooth being higher in the center than along the edges. The adoral end of the plate is the same as seen in the previous view, but the aboral end is different. There is now one pit—on the side adjacent to the vertebral column—on the aboral margin. This pit is very shallow and appears to have acted as an area of attachment for some tendon. There is, however, on the side distal from the vertebral column near the aboral margin an area which is slightly raised above the general surface of the aboral process. This forms a shallow concave area aboral of this raised area and a much deeper concave area adoral near the side adjacent to the vertebral column just where the process begins to swell out.

Turning the plate over so that a side view (Plate V, Fig 3) is obtained the following can be observed. This side, which is uppermost, is the side which is adjacent to the vertebral column. There is a distinct ridge running the entire length of the plate. This ridge is the base of the high ridge which was spoken of in the ventral view. The ventral edge —of the central ridge—rises at the adoral end of the plate

and increases in size until in about the center of the plate where it reaches its maximum. From here to the aboral end it decreases, but does not die out entirely. The surface of the shaft itself is—as in the dorsal view—gently rounded. The surface of the process rises suddenly near the aboral end. At the aboral end one sees a cross-section of the pit seen in the ventral view and the shallow pit for the tendon attachment seen in the dorsal view. On the dorsal side of the process can be seen one of the shallow concave areas spoken of in the dorsal view.

The plate is 4.26 mm. long and 1.23 mm. broad at the aboral end.

First Vertebral Ossicle

Plate VI, Figs. 11-15

Viewing the first vertebral ossicle of *Ophiura sarsii* from the adoral side (Plate V, Fig. 11) the two outstanding features first distinguished are the two centrally located condyles of the zygapophyses against the background of the circular-shaped ala. Taking the ala first it may be described as follows: It has a general circular shape, being notched on the dorsal and ventral sides. The dorsal notch is the upper canal furrow and the much deeper ventral notch is the lower canal furrow. The surface of the ala is divided into two portions: the upper—which is very large and contains the zygapophyses—and the lower part. The surface of the ala is very undulating and not smooth, and it rises to a ridge running diagonally from the lateral ventral corners of the zygapophyses to the circumference of the ala. This ridge divides the ala into two parts. There is a depression that runs vertically from the lower canal furrow to the upper canal furrow which separates the two zygapophyses.

The second outstanding feature on the adoral side of the ossicle are the zygapophyses. These in form are modified rectangles whose longest dimension is vertical. The surface of the ala rises suddenly to form these steep-sided zyga-

pophyses whose outside lateral edges are overhanging. The lower half of the inside of the zygapophyses is deeply recessed. The dorsal side rounds into the outside lateral side. The ventral side is less rounded being more square shaped. The adoral surface of the zygapophyses is convex with a triangular depression in the center of each. The apex of this triangular depression is directed inward. It is this adoral side of the first vertebral ossicle to which the jaws are loosely articulated.

Turning the plate over so that the aboral side (Plate VI, Fig. 12) is seen the following features can be observed: The large muscle areas and the articular area in the center of the plate. The articular area is decidedly different from that found on the adoral side of the plate. The circumference of the parapophyses is the same as that of the upper portion of the ala. However, the upper canal furrow does not indent the parapophyses as much as it did the ala. There is a deep rounded indentation on the circumference of the parapophyses which divides it from the anterior hypapophysis. The lower canal furrow bisects this hypapophysis. There is a ridge which separates the surface of the parapophysis from the hypapophysis. The surfaces of both these areas are undulating, rising from the center of the plate towards the periphery and towards the ridge which separates the two areas.

The surface of the aboral side rises in the center of the plate and forms three articulating condyles—two zygocondyles and one zygosphene. The zygosphene, which is elongated vertically, is situated in about the center of the plate just above the lower canal furrow. There is a very slight groove running vertically up the aboral surface of the zygosphene which is a vestige of the stage when the ossicle consisted of two plates. The dorsal end of the zygosphene is saddled by two zygocondyles. These zygocondyles are larger and not quite so regular in shape as the zygosphene. However, all three bear a close resemblance to grains of rice. The outside margins of all three condyles are perpendicular—to over-

hanging—with respect to the general surface of the plate. Between the two zygocondyles there is a deep furrow which is wider dorsally. This furrow acts as the socket of the condyle belonging to the adjacent vertebral ossicle.

In the lateral view (Plate VI, Fig. 13) of the ossicle the zygapophyses is seen protruding from one side, the zygocondyle from the other. The zygapophysis extends from the center of the adoral surface as a large well-rounded dome with a V-shaped sinus situated in the middle. The ala rises at right angles from the zygapophysis. The lateral edge of the ala is seen forming a modified sigmoid outline. The ventral end of the ala—lower alar ridge—becomes the posterior hypapophysis. On the aboral side the zygocondyle is seen just a little dorsally of the center of the surface. This zygocondyle protrudes from the surface of the parapophysis as an equilateral straight-sided projection whose apex is rounded off. Just ventral to the zygocondyle there can be seen a small rounded condyle which is the zygosphene. The lateral edge of the parapophysis makes a slightly concave arch whose ventral end is just below the zygocondyle. Ventrally of this, the anterior hypapophysis can just be seen forming the ventral portion of the aboral side of the plate. Between the upper alar ridge and the parapophysis is a slight groove which runs down the lateral side of the plate until it gradually disappears about in the center.

Between the posterior hypapophysis and the anterior hypapophysis there is a deep rounded sinus on the ventral margin of the plate. This sinus is continued on the lateral margin of the plate as a deep groove which runs up the lateral side a short distance and its dorsal end is obscured from view by the lower end of the parapophysis. At the dorsal end of this groove there is a hole—which cannot be seen in this view—for the canal of the podia. It is partly in this that the podium is situated.

Viewing the vertebral ossicle from the dorsal side (Plate VI, Fig. 14) both the adoral and aboral sides appear to be

very complicated with their respective articulating areas protruding from their surfaces. On the adoral side of the plate can be seen the two well rounded centrally located zygapophyses each showing an indentation on their respective apices. Towards the lateral sides of the plate the corners of the lower alar ridge can be seen protruding. On the aboral side of the plate the zygosphene can be seen centrally located with its shallow groove so well seen in the aboral view. Flanking the zygosphene on both sides can be seen the two zygocondyles, while on the outside of these can be seen the ventral edges of the anterior hypapophysis.

The dorsal surface of the plate, which is arched transversely, is made up of two ridges and a groove between. These ridges outline a narrow V-shaped groove which is wider at the center and both ends than elsewhere. The ridge on the adoral side is the upper alar ridge while the one on the aboral side is the dorsal ridge of the parapophysis. In the center of the arched dorsal surface there is an indentation which is the upper canal furrow.

The outline of the ventral surface (Plate VI, Fig. 15) of the plate is very similar to that of the dorsal surface, while the surface itself is very complex in comparison. On the adoral side are the two well-rounded centrally located zygapophysis and further towards the lateral sides of the plate are the corners of the lower alar ridge. On the aboral side, the centrally located zygosphene is seen flanked by the two zygocondyles. The groove which is not only seen on the aboral end of the zygosphene can be seen on the ventral side of this condyle.

The ventral surface—which is complex—is divided into two parts by the deep lower canal furrow which runs radially across the center of the plate from the base of the zygosphene to the adoral side. From this straight-sided lower canal furrow the surface rises on both sides into the region which gives rise to the ventral edges of the posterior hypapophysis on the adoral side, and the anterior hypapophysis on the

aboral side. Between these two ridges is a valley which assumes the arched shape of the surface and becomes wider near both ends. The outer end of this valley curves down and under and forms the groove—seen in the lateral view—for the podia. The canal for the podia can be partly seen. Near the adoral end of the lower canal furrow are two holes—one on each side—which connect by a canal to the openings on the lateral side of the plates.

The type plate is 1.46 mm. from the base of each canal furrow on the adoral side, .84 mm. long at greatest dimension, and 2.86 mm. wide across the face of the ala at greatest dimension.

OTHER VERTEBRAL OSSICLES

PLATE VI, Figs. 17, 18

As I have stated above the aboral side of the vertebral ossicles are all the same except for a few modifications which are due to the differences of age of each individual arm segment. However, there is a great difference between the adoral side of the first vertebral ossicle and the adoral side of the other vertebral ossicles. Therefore, I will describe the adoral side of one of the other vertebral ossicles and make no reference to the other five sides.

The ala is the same shape as found in the first vertebral ossicle, with its upper canal furrow and deep lower canal furrow. The difference is in the articulating area, for instead of the two large zygapophysis there is a small rounded condyle situated dorsally of the center of the disk. This condyle is divided vertically down the middle by a very narrow groove. This groove is wider near its dorsal end. This condyle is not completely round for on its ventral side there is a narrow ridge running down towards the ventral margin of the plate. When this ridge reaches the center of the plate it splits and each half widens to form a large triangularly-shaped condyle separated by a deep pit. These two condyles are broader at their dorsal end and taper to a point at the

dorsal end of the lower canal furrow. The deep pit that separates these two condyles is very deep and rounded at both ends. From this short description the decided differences of the adoral surface of the first vertebral ossicle and any of the other vertebral ossicles can readily be seen.

COMPARISON OF OPHIURA MARYLANDICA WITH OPHIURA TEXTURATA AND OPHIURA SARSII

In comparing the fossil species with the two recent ones I will take each plate and state the points of similarity and the differences found in them. In this way I hope to point out the changes and the probable relationship between *Ophiura marylandica* and *O. sarsii* and *O. texturata*. *O. sarsii* is very prolific and very widely distributed throughout the world, while *O. texturata* is an Old World species. It is to this latter species that the fossil one is more closely related, as will be seen later in this comparison of the separate plates.

At the outset let me state that the two recent animals are larger than the fossil, as can be noted by comparing the measurements of the separate plates of all three species. First let us examine the dorsal side of the three different species. The arrangement of the dorsal disk plates of *O. texturata* and *O. sarsii* is very similar; as is also the shape. These plates in *O. marylandica* are similarly arranged, but they are fewer in number as can be seen in the reconstructed disk of the latter in t. f. 5. There is, in all three species, a central disk plate which is either five sides or nearly circular. In all cases this central disk plate overlaps the neighboring plates.

The radial shields all have a similar shape which is slightly modified in each individual. The outside margin of the radial shield of *O. marylandica* is straight while that of *O. sarsii* is undulating. The same side in *O. texturata* is also undulating, but not so pronouncedly. The outside and the inside margins of all three plates are beveled, but the edges of the

plates belonging to *O. sarsii* and *O. texturata* are beveled at a lower angle and thus more of the plates are covered by the neighboring disk plates. On the internal side of these plates there is a condyle at the aboral-internal corner. This condyle is hardly developed at all in *O. marylandica.* In *O. sarsii* this condyle is prominent and forms two raised areas which run in a transverse direction across the aboral end of the plate. This articulating area is very similar to that of *O. marylandica,* but more fully emphasized. In *O. texturata* the condyle runs in a radial direction near the aboral-inside corner of the plate. In this case it is not divided into two parts. Thus we have in the radial shield of *O. marylandica* a combination of features found in the two recent species.

The next outstanding plate on the dorsal side is the comb plate. This is a very important plate in the classification and determination of these species. The comb plates of the three species are all similar in shape except that those of *O. texturata* are a little wider than those of the other two. In all three species they are overlapped about the same amount by neighboring plates. The outstanding feature is the number of comb papillae each species possesses. There are in *O. sarsii* from 9-15 small papillae arranged along the inner margin of the plate. In *O. texturata* the number of such papillae is about 30. In the fossil species, *O. marylandica,* I have counted the distinct sockets of 12 papillae on several comb plates. This number falls within the range found on the comb plate of *O. sarsii.* In the two recent species, the papillae of *O. texturata* are long and stylus-shaped while those of *O. sarsii* are short and stocky. What the shape of those of *O. marylandica* were I do not know, for I found none among all the plates worked with which could be certainly identified. In the case of the comb plates, we have an animal which can be said to be more similar to *O. sarsii.*

Taking the interradial marginal plates next we find that *O. marylandica* has the best developed ones of all the three species. Such plates are present in *O. sarsii,* but they are

small and are not one of the outstanding plates of the disk. Their area of attachment on the internal surface is not as strongly developed as in *O. marylandica.* In the species *O. texturata* these plates are either totally lacking as outstanding plates or they are the same or smaller in size than the neighboring ones. Again we have the fossil species more closely related to *O. sarsii* than to *O. texturata.*

Now turning to the dorsal arm plates for comparison we find that *O. marylandica* has certain characteristics in common with both of the recent species. Take the first ones near the base of the arm we find that *O. marylandica* has four distinctive ones, *O. texturata* also has four while *O. sarsii* sometimes has five. The first dorsal arm plate of *O. sarsii* is more like that of the fossil one than the first dorsal arm plate of *O. texturata.* However, the second, third, and fourth dorsal arm plates of *O. texturata* are very similar in shape to those of *O. marylandica.* Also on the adoral side of the second dorsal arm plate of *O. texturata* are two small teeth. On many of the dorsal arm plates of *O. marylandica* teeth are found along the adoral margin. In no case did I find any traces of teeth on the dorsal arm plates of *O. sarsii.* Also not in all cases were like teeth found in *O. texturata.* The gradation in shape and size are similar, but the arms of *O. sarsii* taper more gradually than *O. texturata,* therefore, it is much longer. Summing up all the points regarding the dorsal arm plates we find that those of *O. texturata* are more similar to *O. marylandica* than those of *O. sarsii.*

Reversing the animal so that the ventral side is observed, the oral shield is the most prominent plate to be seen. These plates are similar in all three species with the exception of a few minor variations. The oral shield of *O. texturata* is longer in proportion than in the other two species. The one illustrated is, however, more irregular than is customary in this species. The proportions of the oral shield of *O. sarsii* and *O. marylandica* are nearer than that found in other species. However, the indentations at the ends of the proximal angle

of *O. texturata* are developed like those of *O. marylandica.* Thus it is hard to state to just which of the recent species *O. marylandica* is most closely related.

With regard to the side mouth shields we find that those of *O. marylandica* are very similar to those of *O. texturata.* Their breadth and length have about the same proportions while the side mouth shield of *O. sarsii* is longer in proportion to its width than in the other two species. In the case of both *O. marylandica* and *O. texturata* there is a small projection on the inside base of the apophysis on the internal surface of the plate. In *O. sarsii* this apophysis is smooth. From this evidence the balance swings towards *O. texturata.*

The ventral arm plates of *O. marylandica* and *O. texturata* are similar in the case of the first ventral arm plate and the other ventral arm plates. Those plates in *O. sarsii* are different, the first one being much thicker and more irregular than in the other species. The other ventral arm plates have more pointed lateral ends and are wider in proportion to their length than in *O. texturata* and *O. marylandica.* Again *O. marylandica* and *O. texturata* are very similar.

With reference to the spines we find that those of *O. sarsii* are very long and stylus-shaped, while those of *O. texturata* are shorter and more blunt. All of the spines found of *O. marylandica* were very short. Once again the similarity between *O. marylandica* and *O. texturata* is brought out.

The teeth of *O. sarsii* are larger than those of *O. texturata.* It is unsafe to make a comparison of the teeth of these recent species with those found belonging to *O. marylandica.* Only a few teeth were found and these could have been from a young animal. Therefore, I will not try to draw any comparison either between the teeth or the torus angularis of *O. marylandica* and the two recent species.

The only other external plates left to discuss are the lateral arm plates and these are divided up into two groups; those belonging to the first three segments at the base of the arm

and those which make up the rest of the arm. I will compare the first and second lateral arm plates of these three species. The first lateral arm plates of these three species are similar with one exception. In *O. sarsii* the first lateral arm plates are in contact with each other medianly while in *O. marylandica* and *O. texturata* they do not meet. The median opening between the lateral arm plates in these two species acts as a pore. This pore is found in about the first nine segments of *O. texturata* when the arm is made up of about 45 segments. It is safe to postulate that the like condition existed in *O. marylandica.* This median pore is one of the distinguishing features of the species *O. texturata.* This same characteristic exists in the second lateral arm plates of these three species. Here we have evidence again of the similarity between *O. marylandica* and *O. texturata.*

The other lateral arm plates of the three species are all similar and do not show any extreme differences. Their change from mature to young plates is similar and, therefore, there can be no great distinction between the fossil and the two recent species. The number of spines on the recent forms varies, but the sockets on *O. marylandica* are too indistinct for comparison.

There are now left just three plates to compare and all three are located within the animal itself. These three are the genital plates, the jaws and the vertebral ossicles. I will compare them in this order and leave the most important—the vertebral ossicles—until last. In general the characteristics of the genital plates of all three species are the same. In *O. sarsii* there is a high narrow ridge which runs down the ventral surface of the shaft on the side distal from the vertebral column. This high ridge is not found in the other two species, their configuration being nearly the same. The articulating surface on the aboral ends of all three species is similar. Thus *O. marylandica* and *O. texturata* are similar in the case of this plate.

The shape and ornamentation of the jaws of the three species are extremely similar except in a ridge which crosses the outside margin of the plate and the aboral end of the plate. This ridge crosses the outside of the plate in a diagonal direction from near the adoral-ventral corner to near the opposite corner, in both *O. marylandica* and *O. texturata.* In *O. sarsii* this ridge is confined to the ventral margin of the plate. This ridge is, however, slightly curved in *O. texturata* whereas in *O. marylandica* it is straight. Again *O. marylandica* is more like *O. texturata* than *O. sarsii.*

Now the last, but by no means the least of the comparisons is that of the vertebral ossicles of the three species. I will compare the adoral and aboral articulating areas of the first vertebral ossicle and the same surface found in an ossicle of a somewhat younger stage—about the fourth vertebral ossicle. The dorsal, ventral, and lateral views will be sufficient for the comparison. To take the adoral articulating surface of the first vertebral ossicles of the three species we find the zygapophyses are similar, but not exactly alike.

The inside margins are closed in *O. sarsii* a little farther apart in *O. marylandica,* and very widely separated in *O. texturata.* In the central groove between the two zygapophyses in *O. texturata* there is a small rounded knob which is lacking in the other species. The aboral side of the articulating areas of *O. marylandica* and *O. texturata* are very similar. The zygocondyles are placed in the same relative positions with reference to the zygosphene in both *O. marylandica* and *O. texturata.* There is a difference in position of these condyles in *O. sarsii.* Thus the first vertebral ossicle of *O. marylandica* is similar on the adoral side to *O. sarsii* and on the aboral side to *O. texturata.*

Taking another of the ossicles located near the first vertebral ossicle so that it will be fully developed, there appears to

be a great diversity in the articulating areas in the three species. The adoral articulating surfaces are decidedly unlike in all three species. In the case of the aboral articulating areas those of *O. marylandica* and *O. texturata* are similar while that of *O. sarsii* is different, as was the case in the first vertebral ossicle. Again *O. texturata* is closer in comparison to *O. marylandica than O. sarsii* is.

Now with all these comparisons of the separate plates of the three species we find that in certain points certain of the plates of *O. sarsii* and *O. marylandica* are similar, while in other plates the similarities are between *O. marylandica* and *O. texturata.* Upon summing up the similarities and the differences we find that *O. marylandica* is more like *O. texturata* than *O. sarsii.* This is brought out by the following tabulation. There appears to be a very close similarity between *O. sarsii* and *O. marylandica* when the comb plates and the interradial marginal plates are considered. A like similarity exists between *O. texturata* and *O. marylandica* in the following plates: Dorsal arm plates, mouth shield, first ventral arm plates, ventral arm plates, spine, first and second lateral arm plates, genital plates, jaws, and vertebral ossicles. Some of the plates in *O. marylandica* combine the characteristics found in both *O. sarsii* and *O. texturata.* These are the oral shields and the first vertebral ossicles. In other plates there is a combination of the features of all three species, these plates are the central disk plate, the radial shield and the lateral arm plates.

Why cannot it be said that, since *O. texturata* has so many characteristics in common with *O. marylandica,* it is the living representative of this Miocene species? The answer is: Because the similarities which exist between *O. sarsii* and *O. marylandica* are very important ones in the classification of the recent species. Thus apparently these two living species are probably the direct descendants of this Miocene form.

SUMMARY

To sum up briefly all the preceding facts one finds the following: That I have a number of separate plates belonging to an ophiuran of Miocene age. These plates were found in the St. Mary's formation just south of Little Cove Point Calvert County, Maryland. All of these separate plates have been proven to fall within the range of variation of one species. Why only one species? Because they could be divided up into a number of different varieties and there were no contrasting ones which could have belonged to another species. Also if Jordan's law, which holds for the present day, is applied during the Miocene it would be directly violated by having two species so similar in all parts but one, living in the same locality. Thus all of the plates are considered to belong to a single species.

From my preceding minute comparison of the separate plates belonging to the three species, *Ophiura marylandica, O. texturata,* and *O. sarsii* one is able to see the resemblances and differences which exist between these three species. By this comparison it is evident that the Miocene species *O. marylandica* is more closely related to *O. texturata* than to *O. sarsii.* It is, therefore, proper and logical to conclude that *Ophiura marylandica* is an extinct species which lived during Miocene times and from which the two very closely similar recent species (*O. texturata* and *O. sarsii*) are probably descended.

What was the range of this Miocene Ophiuran, why it became extinct, why its closest descendants now live in European waters, I dare not postulate. However, with more work in the future on these little animals I may be able to answer a few of these questions. Thus it is also easy to conclude that additional and similar work should be done with other fossil as well as with the recent Ophiuroidea.

EXPLANATION OF PLATES

PLATE I

Ophiura marylandica n. sp.

Fig. 1. Series of dorsal arm plates. x8
Fig. 2. Ventral view of side mouth shield. x8
Fig. 3. Dorsal view of side mouth shield. x8
Fig. 4. Disk plate, exterior view. x8
Fig. 5. Disk plate, interior view. x8
Fig. 6. Right comb plate, exterior view. x8
Fig. 7. Right radial shield, dorsal side. x8
Fig. 8. Right radial shield, ventral side. x8
Fig. 9. Right comb plate, interior view. x8
Fig. 10. First ventral arm plate, ventral side. x8
Fig. 11. First ventral arm plate, dorsal side. x8
Fig. 12. Central disk plate, dorsal side. x8
Fig. 13. Lateral arm plate, exterior view. x8
Fig. 14. Lateral arm plate, interior view. x8
Fig. 15. Lateral arm plate, interior view. x8
Fig. 16. Dorsal arm plate, interior side. x8
Fig. 17. Interradial marginal plate, interior side. x8
Fig. 18. Interradial marginal plate, exterior side. x8
Fig. 19. Second dorsal arm plate, adoral view. x8
Fig. 20. Third dorsal arm plate, adoral view. x8
Fig. 21. Fourth dorsal arm plate. x8
Fig. 22. Disk plate. x8
Fig. 23. Tooth. x32
Fig. 24. Disk plate. x8
Fig. 25. Disk plate. x8
Fig. 26. Spine. x32
Fig. 27. Ventral arm plate, exterior view. x8
Fig. 28. Ventral arm plate, interior view. x8
Fig. 29. Undeterminable plate of similar structure. x32
Fig. 30. Oral shield, ventral side. x8
Fig. 31. Oral shield, dorsal side. x8

PLATE II

Ophiura marylandica n. sp.

Fig. 1. First lateral arm plate, right and left, ventral view. x8
Fig. 2. First lateral arm plate, right and left, interior view. x8
Fig. 3. First lateral arm plate, right and left, dorsal view. x8
Fig. 4. First lateral arm plate, right and left, exterior view. x8

Fig. 5. Torus angularis, adoral side. x32
Fig. 6. Genital plate, ventral side. x8
Fig. 7. Genital plate, dorsal side. x8
Fig. 8. Genital plate, lateral side. x8
Fig. 9. Disk plate. (?) x32
Fig. 10. First vertebral ossicle, adoral side. x8
Fig. 11. First vertebral ossicle, aboral side. x8
Fig. 12. First vertebral ossicle, lateral side. x8
Fig. 13. First vertebral ossicle, dorsal side. x8
Fig. 14. First vertebral ossicle, ventral side. x8
Fig. 15. Second lateral arm plate, left, ventral view. x8
Fig. 16. Second lateral arm plate, left, interior view. x8
Fig. 17. Second lateral arm plate, left, dorsal view. x8
Fig. 18. Second lateral arm plate, left, exterior view. x8
Fig. 19. Dorsal view of oral shield with two side mouth shields attached. x8
Fig. 20. Jaw, right and left, dorsal view. x8
Fig. 21. Jaw, right and left, inside view. x8
Fig. 22. Jaw, right, outside view. x8
Fig. 23. Jaw, right and left, ventral view. x8
Fig. 24. Jaw, aboral view. x8
Fig. 25. Vertebral ossicle, adoral side. x8
Fig. 26. Vertebral ossicle, aboral side. x8

PLATE III

Ophiura texturata

Fig. 1. Genital plate, left, ventral side. x8
Fig. 2. Genital plate, left, dorsal side. x8
Fig. 3. Genital plate, left, lateral side. x8
Fig. 4. Comb plate, left, dorsal side. x8
Fig. 5. Comb plate, left, ventral side. x8
Fig. 6. First dorsal arm plate, dorsal view. x8
Fig. 7. Second dorsal arm plate, dorsal view. x8
Fig. 8. Third dorsal arm plate, dorsal view. x8
Fig. 9. Fourth dorsal arm plate, dorsal view. x8
Fig. 10. Radial shield, left, dorsal side. x8
Fig. 11. Radial shield, left, ventral side. x8
Fig. 12. Jaws, right and left halves, dorsal view. x8
Fig. 13. Jaws, left half, inside view. x8
Fig. 14. Jaws, right and left halves, ventral view. x8
Fig. 15. Jaws, right half, outside view. x8
Fig. 16. Jaws, aboral end. x8

PLATE IV

Ophiura texturata

Fig. 1. First lateral arm plate, left, ventral view. x8
Fig. 2. First lateral arm plate, left, interior view. x8
Fig. 3. First lateral arm plate, left, dorsal view. x8
Fig. 4. First lateral arm plate, left, exterior view. x8
Fig. 5. Side mouth shield and attached plate. x8
Fig. 6. Side mouth shield and attached plate. x8
Fig. 7. Lateral arm plate, right, exterior view. x8
Fig. 8. Lateral arm plate, right, interior view. x8
Fig. 9. Ventral view of side mouth shield, left. x8
Fig. 10. Dorsal view of side mouth shield, left. x8
Fig. 11. First vertebral ossicle, adoral side. x8
Fig. 12. First vertebral ossicle, aboral side. x8
Fig. 13. First vertebral ossicle, lateral side. x8
Fig. 14. First vertebral ossicle, dorsal side. x8
Fig. 15. First vertebral ossicle, ventral side. x8
Fig. 16. Vertebral ossicle, adoral side. x8
Fig. 17. Vertebral ossicle, aboral side. x8
Fig. 18. First ventral arm plate, exterior view. x8
Fig. 19. First ventral arm plate, interior view. x8
Fig. 20. Ventral arm plate, exterior view. x8
Fig. 21. Ventral arm plate, interior view. x8
Fig. 22. Oral shield, ventral side. x8
Fig. 23. Oral shield, dorsal side. x8

PLATE V

Ophiura sarsii

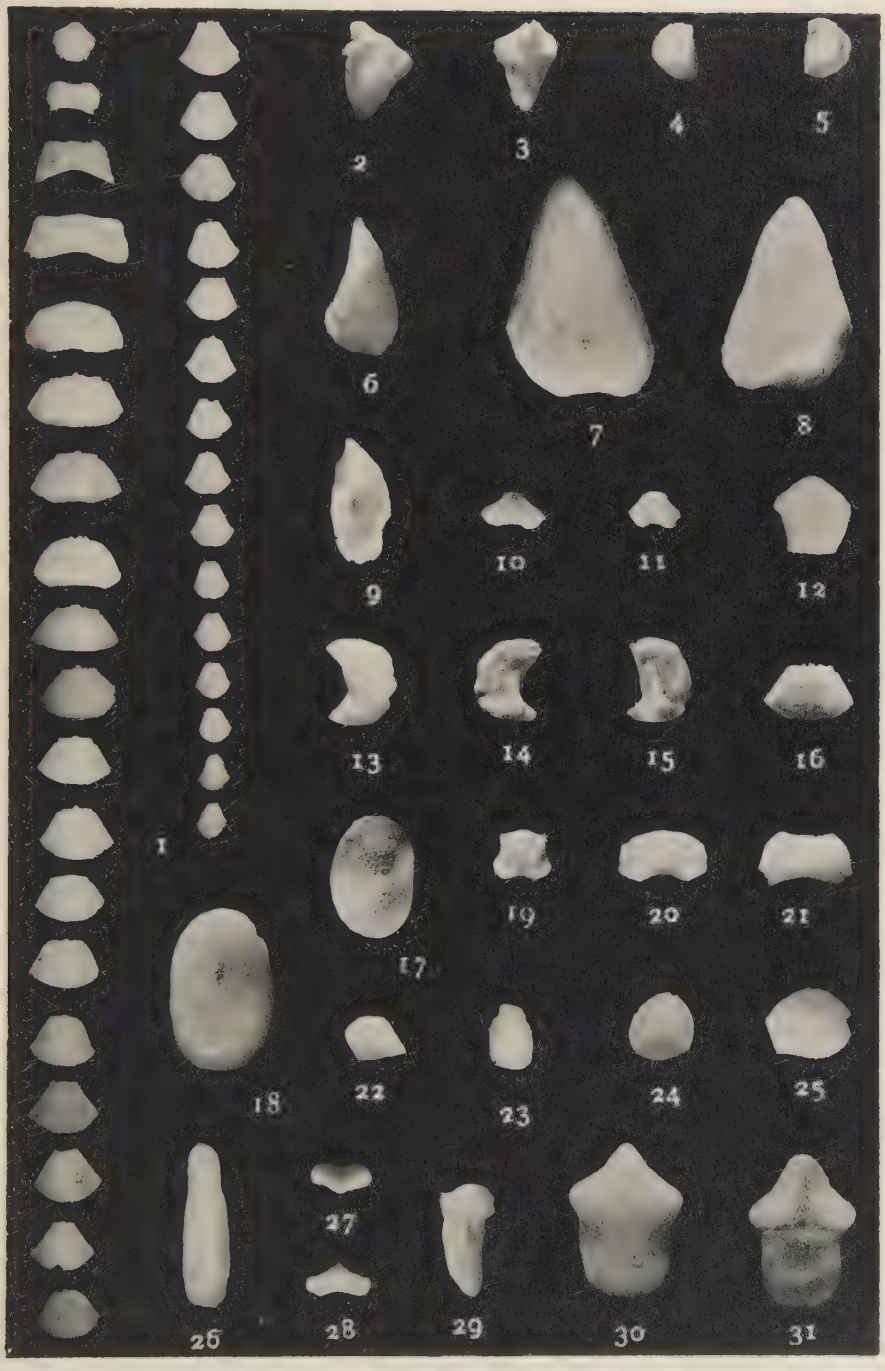
Fig. 1. Genital plate, ventral side. x8
Fig. 2. Genital plate, dorsal side. x8
Fig. 3. Genital plate, lateral side. x8
Fig. 4. Comb plate, right, dorsal side. x8
Fig. 5. Comb plate, right, ventral side. x8
Fig. 6. First dorsal arm plate, dorsal view. x8
Fig. 7. Second dorsal arm plate, dorsal view. x8
Fig. 8. Third dorsal arm plate, dorsal view. x8
Fig. 9. Fourth dorsal arm plate, dorsal view. x8
Fig. 10. First ventral arm plate, interior view. x8
Fig. 11. Jaw, left half, dorsal view. x8
Fig. 12. Jaw, left half, inside view. x8
Fig. 13. Jaw, left half, ventral view. x8
Fig. 14. Jaw, left half, outside view. x8

Fig. 15. Second lateral arm plate, left, ventral view. x8
Fig. 16. Fifth dorsal arm plate, dorsal view. x8
Fig. 17. Second lateral arm plate, left, dorsal view. x8
Fig. 18. First ventral arm plate, exterior view. x8
Fig. 19. Radial shield, right, dorsal side. x8
Fig. 20. Second lateral arm plate, left, interior view. x8
Fig. 21. Second lateral arm plate, left, exterior view. x8
Fig. 22. Radial shield, right, ventral side. x8

PLATE VI

Ophiura sarsii

Fig. 1. First lateral arm plate, left, ventral view. x8
Fig. 2. First lateral arm plate, left, interior view. x8
Fig. 3. First lateral arm plate, left, dorsal view. x8
Fig. 4. First lateral arm plate, left, exterior view. x8
Fig. 5. Ventral view of side mouth shield, right. x8
Fig. 6. Dorsal view of side mouth shield, right. x8
Fig. 7. Lateral arm plate, right, exterior view. x8
Fig. 8. Lateral arm plate, right, interior view. x8
Fig. 9. Interradial marginal plate, exterior view. x8
Fig. 10. Interradial marginal plate, interior view. x8
Fig. 11. First vertebral ossicle, adoral side. x8
Fig. 12. First vertebral ossicle, aboral side. x8
Fig. 13. First vertebral ossicle, lateral side. x8
Fig. 14. First vertebral ossicle, dorsal side. x8
Fig. 15. First vertebral ossicle, ventral side. x8
Fig. 16. Spine. x8
Fig. 17. Vertebral ossicle, adoral side. x8
Fig. 18. Vertebral ossicle, aboral side. x8
Fig. 19. Ventral arm plate, interior view. x8
Fig. 20. Ventral arm plate, exterior view. x8
Fig. 21. Jaw, aboral view. x8
Fig. 22. Oral shield, ventral side. x8
Fig. 23. Oral shield, dorsal side. x8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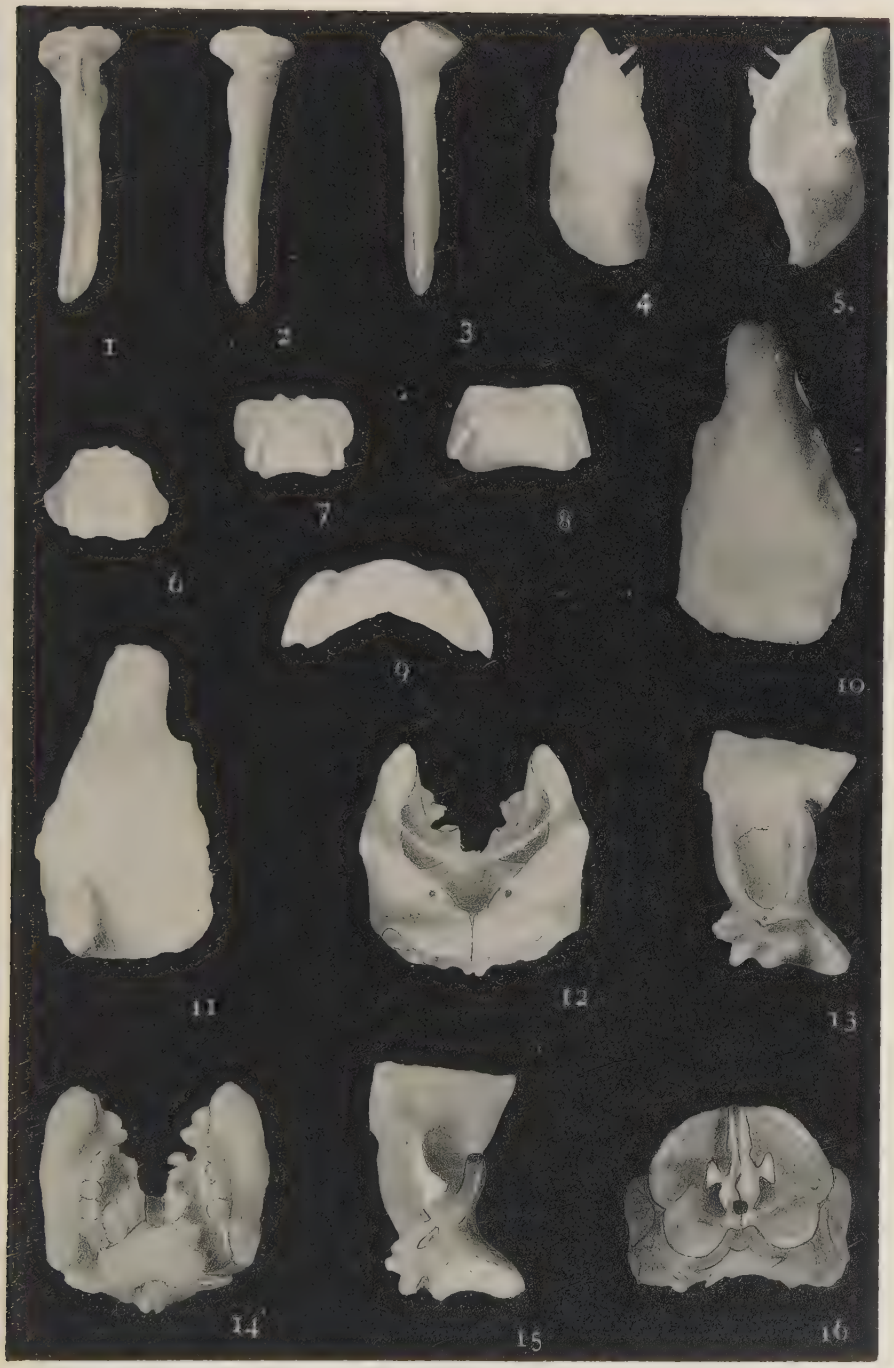
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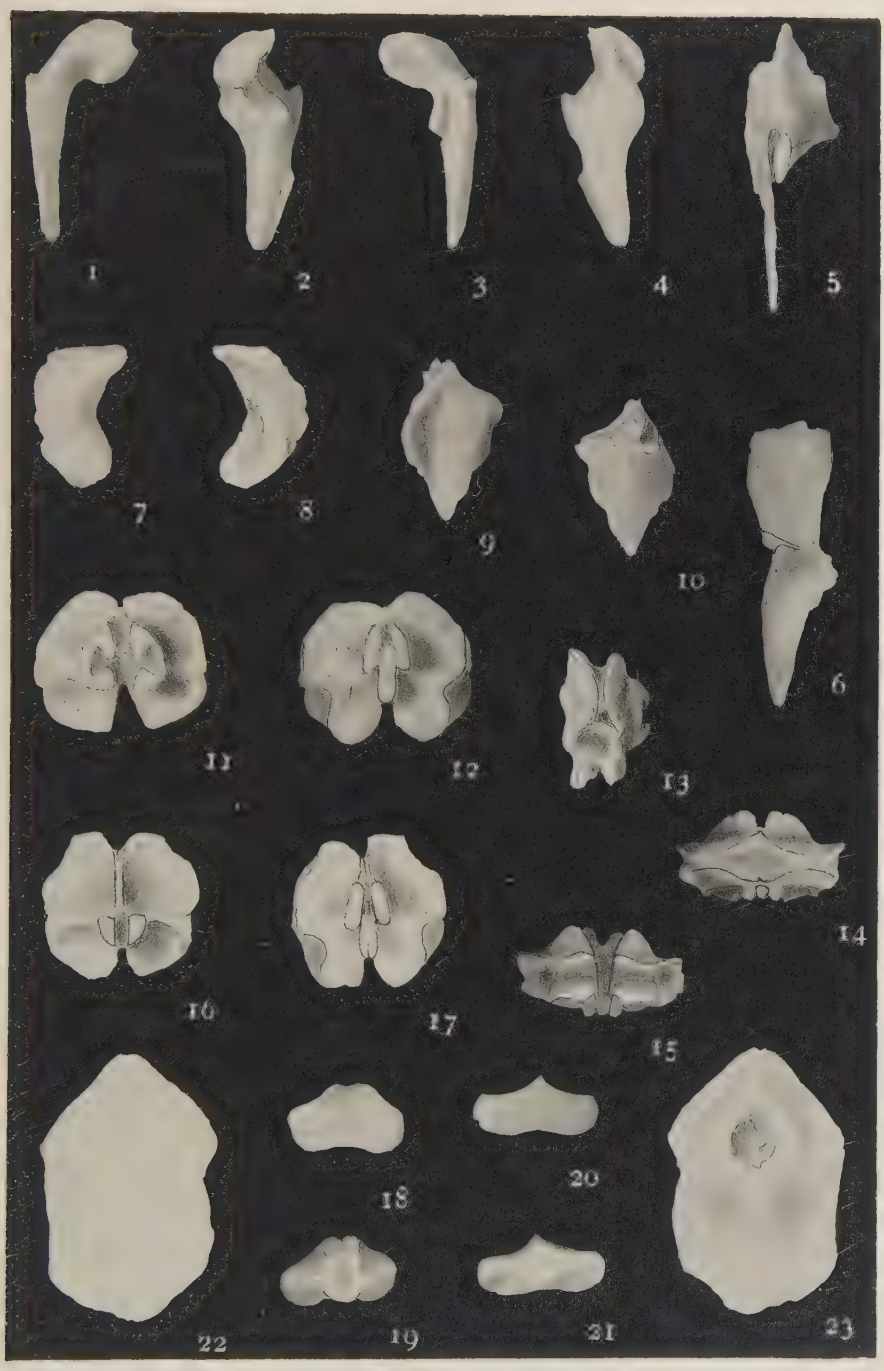
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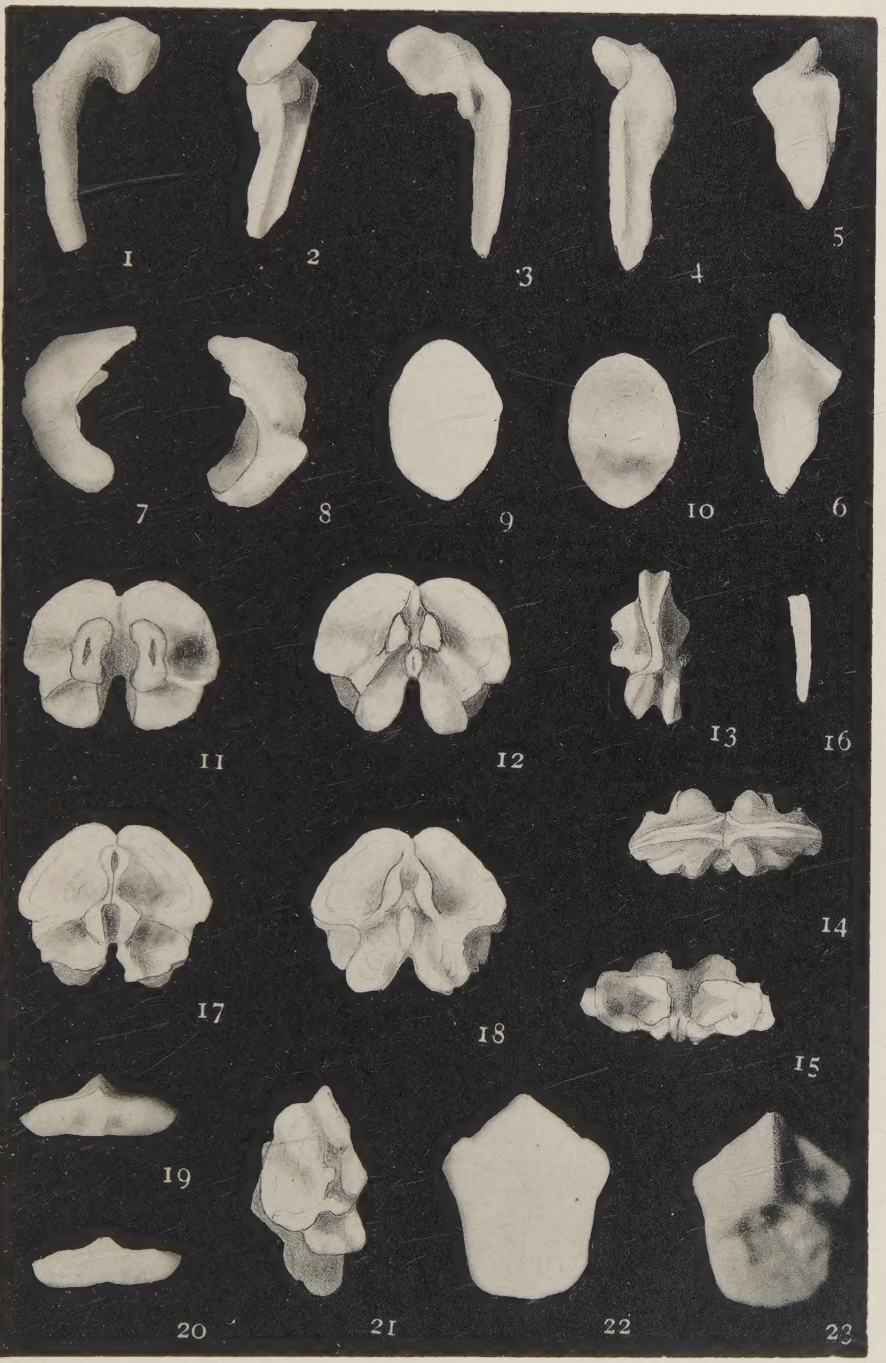
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VITA

Charles T. Berry was born in Baltimore on November 6, 1906. He received his elementary and high school education in the public schools of Baltimore. He entered the Johns Hopkins University as an undergrade in the fall of 1926.

After pursuing the work of an undergrade for three years he was admitted to the Department of Geology in 1929. Since that time he has been in residence as a graduate student. During the summers of 1931 to 1933 inclusive he has worked for the Maryland Geological Survey on different projects within the Costal Plain Region of Maryland.

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He has published:

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